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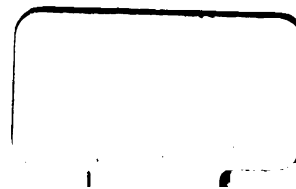

REPORT

OF THE

TESTS OF METALS

AND OTHER MATERIALS

MADE IN THE

ORDNANCE LABORATORY AT WATERTOWN ARSENAL, MASSACHUSETTS, DURING THE FISCAL YEAR ENDED JUNE 30

1917

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

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Dec. 6, 1918.
From
United States Government.

LETTER OF TRANSMITTAL.

WAR DEPARTMENT,
Washington, December 12, 1917.

SIR: I have the honor to transmit herewith the report of the commanding officer of Watertown Arsenal of "tests of iron and steel and other materials for industrial purposes" made at that arsenal during the fiscal year ended June 30, 1917, submitted by the Chief of Ordnance, United States Army, for transmission to Congress as required by law.

Very respectfully,

NEWTON D. BAKER,
Secretary of War.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

LETTER OF SUBMITTAL.

WATERTOWN ARSENAL,
Watertown, Mass., August 22, 1917.

From: Commanding Officer, Watertown Arsenal.
To: Chief of Ordnance, United States Army, Washington, D. C.
Subject: Annual report of Tests of Metals, etc., for the year ending June 30, 1917.

1. The annual report of tests of iron, steel, and other materials made at this arsenal during the fiscal year ending June 30, 1917, is submitted herewith.

2. The total number of specimens tested during the year was 6,404, classified as follows:

For Ordnance Department	5,423
Other Government departments	8
Tests for private parties	973
	6,404

This shows an increase of 10.1 per cent over the figures of last year. (Total number of tests made during 1916 was 5,814.)

3. The receipts and expenditures were as follows:

Amount allotted for testing machine and testing work	$18,900.00
Received from private tests	476.59
Total received	19,376.59
Amount expended for services, labor, etc	11,978.94
Amount expended for light, power, tools, implements, and material for test	7,397.65
Total expended	19,376.59

4. The work of the laboratory has been divided as in former years among the following classes:

(*a*) Routine testing of manufactured and purchased material and tests in connection with current operations of the arsenal.

(*b*) Investigative tests: (1) Material submitted to the department claimed to be of novel or superior value for its use. (2) Material which has developed defects in manufacture or service.

(*c*) Research: Instituted for the purpose of improving ordnance materials, or the technique of their manufacture.

(*d*) Assistance in the manufacturing difficulties of the arsenal.

(*e*) Private tests.

All tests of the above classes are herein reported in such detail as the nature of the tests and importance of information appear to justify. No report is given of the assistance in the manufacturing activities of this arsenal. Such work occupies a considerable portion of the time of the personnel, but report is made only in such cases as require the institution of a research to answer the difficulties. If any such work has been instituted to cover any question which

may have arisen, it will be found reported under the heading "Research instituted for the improvement of ordnance materials, or the technique of their manufacture."

5. A study of the significance of the Charpy shock test is being continued. No separate report has been made on this subject, but practically all the experimental reports contain data which has been derived from results obtained on this machine.

6. Work is still being continued on the subject of gun-wrapping wire. A variety of wires are being studied.

7. A very complete apparatus has been installed for the determination of occluded gases in metals. It is felt that this apparatus is the most complete of the kind which has yet been constructed.

8. Particular attention is also being given to the subject of tensile tests taken in the tranverse direction and the comparison of the results of such test with those obtained from specimens taken from forgings in the longitudinal direction. It would seem from the results of tests already obtained that this field of investigation has been sadly neglected.

9. The following equipment has been added to the laboratory during the current year:

(*a*) Apparatus for determining occluded gases in forged steels.
(*b*) One oscillograph.
(*c*) One apparatus for determining low resistances.
(*d*) One gas furnace.
(*e*) One cathetometer.
(*f*) One flexible disc metal cutter for cutting hardened steel.
(*g*) One single-point potentiometer.
(*h*) One portable potentiometer.
(*i*) Three ammeters.
(*j*) Two multiple unit electric combustion furnaces.
(*k*) One stationary polishing machine.
(*l*) One portable polishing machine.
(*m*) One grinder with motor attached.

10. With the additional equipment referred to above, the laboratory will be able to undertake several investigations which will be of value in the production of ordnance material.

Respectfully,

T. C. DICKSON,
Lieutenant Colonel, Ordnance Department,
United States Army, Commanding.

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REPORT

OF THE

TESTS OF METALS

AND OTHER MATERIALS

MADE IN THE

ORDNANCE LABORATORY AT WATERTOWN ARSENAL, MASSACHUSETTS, DURING THE FISCAL YEAR ENDED JUNE 30,

1917.

ROUTINE TESTING OF MANUFACTURED AND PURCHASED MATERIAL AND TESTS IN CONNECTION WITH CURRENT OPERATIONS OF THE ARSENAL.

CHAIN.

PROOF STRESSES APPLIED TO 11 THREE-FOURTHS-INCH SLING CHAINS FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Chains consisted of about 20 feet of three-fourths-inch chain with a hook at one end and a link at the other. Elongations were measured on a gauge length of 100 inches. The chains were tested in two sections.

	Required.	Sling chains.				
		1	2	3	4	5
Diameter of wire	¾ inch	0.77″	0.77″	0.77″	0.77″	0.77″
Length of link over all		5.07″	5.05″	5.05″	5.05″	5.05″
Width of link		2.52″	2.56″	2.50″	2.52″	2.50″
Maximum load in service	10,400 pounds					
Proof load, pounds	16,500	16,500	16,500	16,500	(1)	16,500
Elongation in 2 inches		5.13″	6.58″	6.18″	.....	5.89″
Elongation, per cent	Not to exceed 10 per cent.	2.56	3.29	3.09	.....	1.44

	Required.	Sling chains—Continued.					
		6	7	8	9	10	11
Diameter of wire	¾ inch	0.77″	0.77″	0.77″	0.75″	0.75″	0.75″
Length of link over all		5.07″	5.05″	5.06″	5.00″	5.00″	5.00″
Width of link		2.56″	2.63″	2.57″	2.60″	2.45″	2.55″
Maximum load in service	10,400 pounds						
Proof load, pounds	16,500	16,500	16,500	16,500	16,500	16,500	16,500
Elongation in 2 inches		5.89″	3.56″	5.95″	5.20″	6.05″	6.25″
Elongation, per cent	Not to exceed 10 per cent.	1.44	1.78	2.97	2.60	3.02	3.12

[1] At 14,700 pounds the ninth link of the chain fractured at the welded end.

PROOF AND TENSILE TESTS OF FOUR PIECES OF ONE-HALF-INCH CHAIN FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Proof tests.

	Required.	Results.			
		1	2	3	4
Diameter of wire, inches	½ inch	0.53″	0.53″	0.53″	0.53″
Length of link over all		2.47″	2.50″	2.45″	2.50″
Width of link		1.85″	1.85″	1.85″	1.67″
Maximum load in service	4,600 pounds				
Proof load, pounds	7,300	7,300	7,300	7,300	7,300
Elongation measured on a gauge length of		100″	100″	100″	150″
Elongation, per cent	Not to exceed 10 per cent.	4.12	3.99	4.15	1.32

Tensile tests.

Number of links taken for test.	Tensile strength (pounds per square inch).		Manner of failure.
	Required.	Results.	
11	14,600	16,200	Fractured second link at the quarter.
11	14,600	17,000	Fractured end link at the quarter.
9	14,600	16,300	Fractured second link at the quarter.
6	14,600	17,400	Fractured the end link.

WIRE ROPE.

WIRE ROPE.

[Rope prepared for testing with closed sockets at the ends.]

Marks.	Nominal size, diameter.	Length between sockets.	Actual size, diameter.	Number of strands.	Number of wires per strand.
	Inch.	*Ft. Inch.*	*Inch.*		
Hoisting rope	¼	9 11	0.27	6	19
Steel wire rope	⅜	9 6	.37	6	19
Plow steel crane rope	⅜	9 7	.38	6	36
Do	⅜	9 7	.40	6	36
Steel wire rope	½	9 7	.53	6	19
Plow steel crane rope	9/16	9 8	.56	8	19
Steel wire hoisting rope	9/16	9 8	.58	8	19
Steel wire rope	9/16	9 7	.59	6	19
Plow steel crane rope	9/16	9 6	.63	8	19
Steel hoisting rope	⅝	9 5	.65	6	19
Plow steel crane rope	¾	9 5	.88	6	37
Do	¾	9 3½	.88	6	37
Do	¾	9 5	.89	6	37
Plow steel wire rope	1	9 5	1.02	6	37
Plow steel crane rope	1	9 5	1.03	6	37

Marks.	Core.	Breaking strength.	Parted.
		Pounds.	
Hoisting rope	Hemp	4,700	4 strands, 28 inches from end of socket.
Steel wire rope	do	10,900	4 strands, 25 inches from end of socket.
Plow steel crane rope	do	10,000	3 strands, at middle of length.
Do	do	11,000	4 strands, at end of socket.
Steel wire rope	do	20,000	3 strands, 23 inches from end of socket.
Plow steel crane rope	do	23,700	5 strands, 1 inch from end of socket.
Steel wire hoisting rope	do	25,100	4 strands, 41 inches from end of socket.
Steel wire rope	do	24,200	6 strands, at middle of length.
Plow steel crane rope	do	27,500	5 strands, 4 feet from end of socket.
Steel hoisting rope	do	26,400	3 strands, 18 inches from end of socket.
Plow steel crane rope	do	53,500	3 strands, 14½ inches from end of socket.
Do	do	60,100	3 strands, 19 inches from end of socket.
Do	do	61,200	4 strands, 32 inches from end of socket.
Plow steel wire rope	do	73,300	3 strands, 47 inches from end of socket.
Plow steel crane rope	do	75,300	3 strands, 21 inches from end of socket.

MANILA ROPE.

MANILA ROPE (3-STRAND).

[Samples prepared for testing with eye splices at the ends and then wetting the rope.]

Nominal size.		Length of sample (feet).	Length between splices (feet).	Actual size.		Sectional area (square inches).	Tensile strength.		Parted.
Diameter (inches).	Circumference (inches).			Circumference (inches).	Diameter (inches).		Load (pounds).	Pounds per square inch.	
[1].20	.....	18	6	.....	.19	.....	.....	276	16 inches from fixture.
⅜	.....	.....	6	1.15	.36	0.102	1,125	11,029	1 strand, 28 inches from end of splice.
⅜	.....	.....	6	1.15	.37	.107	1,200	11,215	1 strand, 15 inches from end of splice.
½	.....	.....	6	1.60	.51	.204	2,300	11,274	1 strand, 17 inches from end of splice.
	2.00	.....	6	2.10	.68	.363	3,300	9,090	1 strand, 21 inches from end of splice.
	2.00	.....	6	2.15	.68	.363	4,400	12,120	1 strand, 19 inches from end of splice.
	2.50	.....	6	2.55	.83	.541	4,600	8,502	1 strand, at middle of length.
	2.50	.....	6	2.70	.86	.580	6,200	10,680	1 strand, 11 inches from end of splice.
	3.00	.....	6	3.15	1.02	.817	9,400	11,505	1 strand, at splice.
	3.00	.....	6	3.25	1.05	.865	7,700	8,900	1 strand, 28 inches from end of splice.
	4.00	.....	6	4.75	1.55	1.886	14,300	7,580	1 strand, 15 inches from end of splice
	[2] 4.00	.....	6	4.25	1.40	1.539	14,100	9,160	1 strand, 18 inches from end of splice.
3.50	.....	.....	5	11.04	3.75	11.04	68,300	6,186	1 strand, at splice.
3.50	.....	.....	5	12.40	4.13	13.39	84,290	6,280	1 strand, at splice.

[1] Braided linen cord.

[2] 4-strand sample.

RUBBER.

RUBBER.

Description.	Thickness (inch).	Width (inches).	Sectional area (square inch).	Tensile strength.		Elongation in 2 inches.	
				Load (pounds).	Stress (pounds per square inch).	Inches.	Per cent.
Covering rubber	0.22	1.02	0.224	160	714	3.06	153.0
Do	.25	1.01	.252	131	519	1.83	91.5
Bead rubber	.26	1.00	.260	148	569	1.71	85.5
Do	.32	1.00	.320	172	537	2.15	107.5
Covering rubber	.40	1.00	.400	338	845	.80	40.0
Do	.41	1.06	.43	630	1,465	6.90	345.0
Do	.41	.94	.38	582	1,531	5.75	287.5
Do	.41	1.03	.42	554	1,319	4.80	240.0
Do	.41	.96	.39	445	1,141	1.81	90.5
Do	.41	.96	.39	454	1,164	3.41	170.0
Do	.55	1.02	.561	410	730	2.00	100.0
Do	.57	.99	.564	575	1,019	1.10	55.0
Do	.58	.98	.568	728	1,281	1.46	73.0

COMPRESSIVE TESTS ON 33 RUBBER TRUCK TIRES FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Compressive loads were applied to the face of the tire on a block 1 inch square. The compression was measured at loads of 500 and 1,000 pounds per square inch. The maximum tolerance at 500 pounds compression was 0.10 inch and at 1,000 pounds compression 0.20 inch.

No.	Applied loads (total pounds).	Compression (inch).
1	500	0.10
	1,000	.18
2	500	.15
	1,000	.25
3	500	.11
	1,000	.19
4	500	.13
	1,000	.22
5	500	.11
	1,000	.19
6	500	.08
	1,000	.16
7	500	.10
	1,000	.19
8	500	.10
	11,000	.18
9	500	.10
	1,000	.19
10	500	.10
	1,000	.19
11	500	.08
	1,000	.15
12	500	.10
	1,000	.16
13	500	.10
	1,000	.18
14	500	.09
	1,000	.16
15	500	.09
	1,000	.15
16	500	.11
	1,000	
17	500	.08
	1,000	.15
18	500	.11
	1,000	.19
19	500	.10
	1,000	.17
20	500	.09
	1,000	.18
21	500	.09
	1,000	.16
22	500	.11
	1,000	.18
23	500	.07
	1,000	.16
24	500	.09
	1,000	.15
25	500	.11
	1,000	.24
26	500	.14
	1,000	.22
27	500	.15
	1,000	.26
28	500	.14
	1,000	.23
29	500	.16
	1,000	.27
30	500	.10
	1,000	.19
31	500	.09
	1,000	.19
32	500	.12
	1,000	.19
33	500	.12
	1,000	.20

HOSE.

PNEUMATIC HOSE.

Gauged length of 2 inches laid off on each sample; stretched to 6 inches for 10 minutes, and load removed.

Tube test.

Description.	Width (inches).	Length (inches).	Permanent set (inches).	Remarks.
7-ply, ½ inch	1.00	6.00		Sample stretched until gauge marks were 5½ inches apart.
Do	1	6	0.18	
Do	1	6		Sample parted outside gauge marks after stretching to 5¾ inches.
Do	1	6	.21	
Do	1	6	.37	
Do	1	6	.22	
7-ply, ¾ inch	1	6	.24	
Do	1	6	.45	
Do	1	6	.20	
Do	1	6		Sample parted after stretching to 5½ inches.
Do	1	6		Parted at gauge mark after being stretched to 6 inches for 4 minutes.
Do	1	6	.50	
Do	1	6		Sample parted between gauge marks after stretching to 4½ inches.
Do	1	6		Parted between gauge marks after stretching to length of 5½ inches.

Friction tests.

Description.	Unwound in 10 minutes (inches).	Remarks.
7-ply, ½ inch	2 90	
Do	8.40	In 2 minutes.
Do	3.10	
Do	.40	
Do	1.47	
Do	3.75	
7-ply, ¾ inch	.60	
Do	4.75	
Do	3.75	
Do	4.75	
Do	3.75	
Do	4.60	
Do	.75	
Do	4.50	
Do	15.25	In 9 minutes.
Do	8.00	
Do	5.25	

PROOF STRESSES ON PISTON RODS.

PROOF STRESSES.

PROOF STRESS APPLIED TO 11 PISTON RODS FOR 3-INCH ANTI-AIRCRAFT MOUNTS FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

[Proof stress required=40,944 pounds tension.]

Elongations measured on a gauge length of 8 inches, the first point in gauge length being 6¼ inches from the piston head.

Number on rods.	Applied loads.		
	500 pounds.	40,944 pounds.	500 pounds.
	Inch.	*Inch.*	*Inch.*
1	0	0.0020	0
2	0	.0023	0
3	0	.0017	0
4	0	.0017	0
5	0	.0020	0.0001
6	0	.0019	0
7	0	.0017	0
8	0	.0016	0
9	0	.0021	0
10	0	.0018	0
11	0	.0023	0

A proof stress of 40,944 pounds tension was applied to each rod.

PROOF STRESS APPLIED TO ONE PISTON ROD FOR 7.6-INCH HOWITZER, MODEL OF 1915, FOR ROCK ISLAND ARSENAL, ROCK ISLAND, ILL.

Elongations measured on a gauge length of 10 inches, the first point in gauge length being 17 inches from the end of piston head.

Applied loads (total pounds).	Elongations in 10 inches (inches).	Set (inch).	Remarks.
1,000	0.0	0	Initial load.
25,000	.0030	0	
50,000	.0060		
75,000	.0081		
100,000	.0103		
125,000	.0125		
150,000	.0148		
175,000	.0171		
196,500	.0191		
1,000	.0009	.0009	Second run on rod. Micrometer reset.
1,000	.0	0	
196,500	.0183		
1,000	.0001	.0001	

PROOF STRESS APPLIED TO TWO PISTON RODS FOR 14-INCH D. C., MODEL OF 1907 MI, FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

[Proof stress required=575,000 pounds tension.]

Elongation measured on gauge length of 30 inches, the first point of gauge length being about 30 inches from piston head.

No. on rods.	Applied loads.		
	5,000 pounds.	575,000 pounds.	5,000 pounds.
	Inch.	*Inch.*	*Inch.*
5935–4	0	0.0249	0
5940–3	0	.0223	0

A proof stress of 575,000 pounds tension was applied to each rod without sign of failure.

SPRINGS.

SPRINGS.

COMPRESSIVE TEST OF TWO RECOIL SPRINGS (RECTANGULAR) FOR 15-POUNDER CARRIAGES FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

For the purpose of making a comparative test with the recoil springs of 15-pounder carriages, model 1898, Nos. 82 and 83, which have been received at this arsenal from Fort Rodman.

Data required.	Spring No. 18.	Spring No. 95.
Free height of spring	21.39 inches	21.44 inches.
Outside diameter	3.77 inches	3.76 inches.
Inside diameter	1.67 inches	1.66 inches.
Size of wire	1.07 by 0.26 inch	1.07 by 0.27 inch.
Number of coils	30	30.
Load at 14.5 inches	1,250 pounds	1,256 pounds.
Load at 9.5 inches	2,135 pounds	2,055 pounds.
Load when solid	2,237 pounds	2,134 pounds.
Height when solid	8.83 inches	9.10 inches.

COMPRESSION TEST OF SIX RECOIL SPRINGS FOR 15-POUNDER CARRIAGES, MODEL 1898, FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

For the purpose of making a comparative test of the recoil springs of 15-pounder carriages, model 1898, Nos. 82 and 83, which have been received at this arsenal from Fort Rodman, and rectangular springs, some of which are on hand in the storehouse.

Test of small or inner springs.

Data required.	Spring from carriage No. 82.	Spring from carriage No. 83.
Free height of springs	16.95 inches	17.29 inches.
Number of coils	23	23.
Size of wire	0.37 inch	0.37 inch.
Load at 14 inches	300 pounds	340 pounds.
Load at 9 inches	795 pounds	875 pounds.

Test of large or outer springs.

Data required.	Spring from carriage No. 82.	Spring from carriage No. 83.
Free height of springs	19.65 inches	19.61 inches.
Number of coils	19	19.
Size of wire	0.50 inch	0.50 inch.
Load at 15 inches	632 pounds	625 pounds.
Load at 10 inches	1,324 pounds	1,336 pounds.

Test of springs assembled—Small spring inside of large one.

Data required.	Spring from carriage No. 82.	Spring from carriage No. 83.
Load at 15 inches	835 pounds [1]	835 pounds.[1]
Load at 10 inches	2,000 pounds	2,070 pounds.
Load when solid	2,330 pounds	2,410 pounds.
Height when solid	9.60 inches	9.70 inches.

[1] Note that in this test inner spring was compressed only to 15 inches, whereas it is actually assembled in carriage at 14 inches. Considering that the inner spring was compressed to 14 inches, these figures would be 935 and 945, respectively.

NOTE.

The assembly under test does not give same conditions as assembled in gun. Under test, the small spring had 1 inch less compression than under service conditions.

SMALL SPRING NO. 82.

Compression $16.95'' - 9'' = 7.95''$.
Total load = load per inch compression.

Compression in inches: $\frac{795}{7.95} = 100$ pounds per inch compression.

Compression of small spring assembled at $15'' = 16.95 - 15'' = 1.95$. $100 \times 1.95 = 195$ load on small spring.

Load on large spring at $15'' = 632$ pounds. $632 + 195 = 827$ pounds = calculated load when assembled for test. Measured load = 835 pounds.

By similar calculations it can be shown that data on assembled springs checks very closely the data obtained on the springs taken separately.

Test of rectangular springs from storehouse.

Data required.	Spring No. 49.	Spring No. 67.
Free height of spring	21.55 inches	21.23 inches.
Outside diameter	3.80 inches	3.78 inches.
Inside diameter	1.67 inches	1.66 inches.
Size of wire	1.07 by 0.27 inch	1.07 by 0.27 inch.
Number of coils	29	30.
Load at 14.5 inches	1,238 pounds	1,234 pounds.
Load at 9.5 inches	2,117 pounds	2,174 pounds.
Load when solid	2,370 pounds	2,320 pounds.
Height when solid	8.5 inches	8.98 inches.

COPPER ROTATING BANDS.

TENSILE TESTS OF SECTIONS OF COPPER ROTATING BANDS.

Band for—	Width (inch).	Thickness (inch).	Sectional area (square inch).	Tensile strength.		Elongation in 2 inches.		Elongation in inch sections.	
				Load (lbs.).	Pounds per square inch.	Inch.	Per cent.	Inch.	Inch.
4.7-inch common steel shell	0.495	0.102	0.050	1,585	31,700	0.79	39.5	0.28	[1] 0.51
Do	.502	.096	.048	1,455	30,312	.64	32.0	.19	[1] .45
Do	.501	.101	.050	1,494	29,900	.75	37.5	.32	[1] .43
Do	.497	.105	.052	1,668	32,077	.85	42.5	[1] .50	.35
Do	.505	.097	.049	1,568	32,000	.79	39.5	.24	[1] .55
Do	.505	.099	.0499	1,625	32,560	.80	40.0	.34	[1] .46
Do	.504	.097	.0488	1,629	33,380	.68	34.0	.18	[1] .50
6-inch A. P. shell	.501	.090	.045	1,575	35,000	.45	22.5	.18	[1] .27
12-inch A. P. shell	.504	.10	.050	1,713	34,200	.70	35.0	.24	[1] .46
Do	.504	.10	.050	1,719	34,360	.72	36.0	.24	[1] .48

Band for—	Dimensions at fracture.			Contraction of area (per cent).	Appearance of fracture.
	Width (inch).	Thickness (inch).	Sectional area (square inch).		
4.7-inch common steel shell	0.35	0.05	0.017	66.0	Salmon.
Do	.36	.04	.014	70.8	Do.
Do	.36	.05	.018	64.0	Do.
Do	.33	.05	.016	69.2	Do.
Do	.35	.07	.024	51.0	Do.
Do	.37	.06	.022	55.9	Do.
Do	.35	.05	.017	65.1	Do.
6-inch A. P. shell	.42	.06	.025	44.4	Do.
12-inch A. P. shell	.39	.07	.027	46.0	Do.
Do	.37	.07	.026	48.0	Do

[1] Inch section in which fracture occurred.

MISCELLANEOUS.

MISCELLANEOUS.

LIBRATION OF DYNAMOMETER.

This machine was calibrated in the large Emery hydraulic testing machine. The dynamometer was supported on the opposite side from the scale and pointer. Three series of readings were taken, the load being applied in the proper increments up to 60 long tons, and then decreased to 5 long tons. This operation was repeated three times. The entire series of readings is tabulated, and for the purpose of plotting the calibration curve the mean values of the "up" readings were used for the graph "Readings with increasing load," and the mean values of the "down" readings for the graph "Readings with decreasing load."

From an inspection of these two graphs, it is to be noted that in no case is the difference between the "up" and "down" readings greater than 1 long ton.

For the purpose of marking the scale, the mean of the "up" and "down" readings were taken at each load. The accuracy of this instrument, therefore, will fall within one-half long ton. To assist in the making of a new scale, a reference mark was stamped on the dynamometer. The distance from this reference mark to the zero point on the scale should be 16.8 centimeters. There was no appreciable movement of the pointer from zero to 5 tons. The accuracy of this instrument below 10 tons is questionable.

"Up" readings.

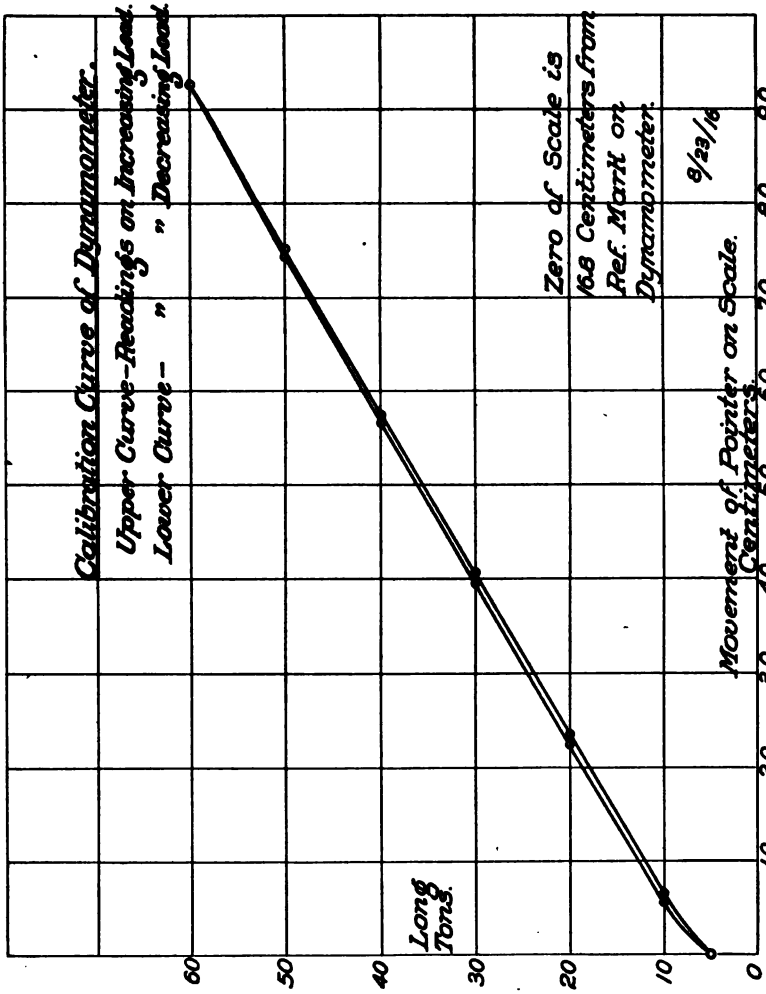
Load tons.	5	10	20	30	40	50	60
Trial No. 1	0	0.55	2.25	3.95	5.65	7.45	9.30
Trial No. 2	0	.55	2.25	3.95	5.65	7.45	9.25
Trial No. 3	0	.60	2.25	3.95	5.70	7.45	9.30
Mean	0	.57	2.25	3.95	5.67	7.45	9.28

"Down" readings.

Load tons.	60	50	40	30	20	10	5
Trial No. 1	9.30	7.55	5.80	4.05	2.35	0.65	0
Trial No. 2	9.25	7.55	5.70	4.05	2.30	.65	0
Trial No. 3	9.30	7.45	5.75	4.10	2.40	.65	0
Mean	9.28	7.52	5.75	4.07	2.35	.65	0

Mean of "up" and "down" readings.

Load tons.	5	10	20	30	40	50	60
	0	0.61	2.30	4.01	5.71	7.49	9.28


Calibration Curve of Dynamometer.
Upper Curve-Readings on Increasing Load.
Lower Curve- " " Decreasing Load.
Zero of Scale is
16.8 Centimeters from
Ref. Mark on
Dynamometer.
9/23/16
Long Tons.
Movement of Pointer on Scale.
Centimeters.
0
10
20
30
40
50
60
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0

TENSILE TESTS OF FOUR WELDED RODS FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Bars marked A, B, C, and E.
A = welded with high carbon (sample) rod.
B = welded with high carbon (sample) rod.
C = welded with Titan rod.
E = welded with Boston C Co.'s rod.

Marks.	Diameter (inch).	Sectional area (square inch).	Approximate yield point.		Tensile strength.	
			Load (pounds).	Stress (pounds per square inch).	Load (pounds).	Stress (pounds per square inch).
A	0.505	0.20	5,400	27,000	6,600	33,000
B	.505	.20	5,200	26,000	5,900	29,500
C	.505	.20	4,300	21,500	5,500	27,500
E	.505	.20	4,800	24,000	5,600	28,000

Marks.	Elongation in 2 inches.		Elongation in inch sections.		Diameter at fracture (inch).	Contraction of area (per cent).	Appearance of fracture.
	Inch.	Per cent.	Inch.	Inch.			
A	0.13	6.5	[1] 0.12	0.01	0.49	5.7	Silvery gray, oblique.
B	.11	5.5	[1].09	.02	.49	5.7	Amorphous.
C	.10	5.0	.02	[1].08	.49	5.7	Silvery gray, oblique.
E	.02	1.0	.01	.01	.50	1.8	Do.

[1] Inch section in which fracture occurred.

TENSILE TEST OF A PIECE OF COLD-DRAWN SEAMLESS STEEL TUBING FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Dimensions.		Sectional area (square inch).	Yield point.		Tensile strength.	
Width (inch).	Thickness (inch)		Total pounds.	Pounds per square inch.	Total pounds.	Pounds per square inch.
0.999	0.379	0.378	17,400	46,000	22,200	58,700

Elongation in 2 inches.		Elongation in inch sections.		Dimensions at fracture.			Contraction of area.	Appearance of fracture.
Inch.	Per cent.	Inch.	Inch.	Width (inch).	Thickness (inch).	Sectional area (square inch).		
0.64	32.0	0.23	[1] 0.41	0.71	0.23	0.163	56.8	Silky.

[1] Inch section in which fracture occurred.

TENSILE TEST OF A SPECIMEN TAKEN FROM A PIECE OF STEEL TUBING FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

	Width (inch).	Thickness (inch).	Sectional area (square inch).	Elastic limit.		Tensile strength.	
				Load (pounds).	Stress (pounds per square inch).	Load (pounds).	Stress (pounds per square inch).
Required					50,000–65,000		60,000–75,000
Result	0.998	0.382	0.381	24,300	63,779	27,500	72,178

	Elongation in 8 inches.		Elongation in inch sections.							
	Inch.	Per cent.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
Required		10–16								
Result	0.68	8.5	0.02	0.04	0.03	0.04	0.05	0.06	[1] 0.26	[1] 0.18

	Dimensions at fracture.			Contraction of area (per cent).	Appearance of fracture.
	Width (inch).	Thickness (inch).	Sectional area (square inch).		
Required				35–45	
Result	0.75	0.25	0.187	50.9	Silky.

[1] Inch section in which fracture occurred.

TENSILE TEST OF A PIECE OF MACHINERY STEEL (PLATE SPECIMEN) FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Width (inch).	Thickness (inch).	Sectional area (square inch).	Yield point.		Tensile strength.	
			Load (pounds).	Pounds per square inch.	Load (pounds).	Pounds per square inch.
0.994	0.184	0.183	7,500	40,980	10,600	57,920

Elongation in 8 inches.		Elongation of inch sections.							
Inches.	Per cent.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
2.21	27.6	0.18	0.20	0.21	0.19	0.27	0.37	[1] 0.54	0.25

[1] Inch section in which fracture occurred.

DIMENSIONS AT FRACTURE.

Width (inch).	Thickness (inch).	Sectional area (square inch).	Contraction of area (per cent).	Appearance of fracture.
0.70	0.10	0.07	61.7	Silky.

PROOF STRESS APPLIED TO ONE ELEVATING SHAFT FOR 16-INCH D. C., L. F., MODEL OF 1912, FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

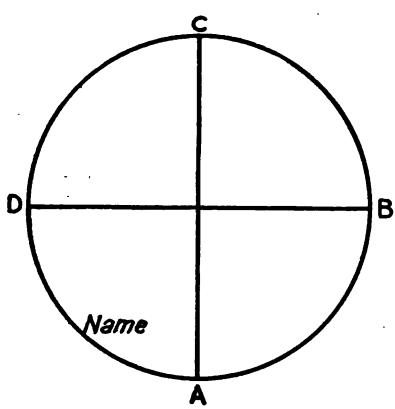
Proof stress required = 400,000 pounds pull between top nut, 41C, and piston.

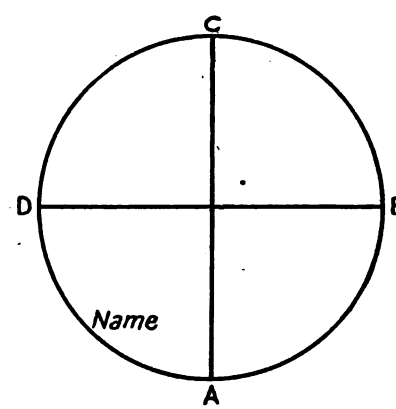
Elongations were taken on a length of about 21.75 inches from outside flange of gear to outside face of a ring threaded on shaft in place of the regular piston. Shaft number, 5975.

Applied roads (total pounds).	Elongation in 21.75 inches (inch).	Set (inch).	Remarks.
5,000	0	0	
100,000	.0141		
200,000	.0202		
5,000		.0109	This set is probably due to a little looseness in thread of ring.
200,000	.0202		
300,000	.0259		
400,000	.0310		
5,000		.0123	
SECOND RUN.			
5,000	0.0123	0.0123	
400,000	.0317		
5,000		.0129	

HARDNESS TEST ON TWO COLD SAWS FOR WATERTOWN ARSENAL, WATERTOWN, MASS.

Brinell hardness taken at four places, or at the quarters about 0.20 inch from the bottom of the teeth.





14½-inch diameter saw.					16⅝-inch diameter saw.			
Points.	A.	B.	C.	D.	A.	B.	C.	D.
Hardness Brinell	478	478	389	389	364	430	364	352

INVESTIGATIVE TESTS.

(Material submitted to the department claimed to be of novel or superior value for its use, or material which has developed defects in manufacture or service.)

INVESTIGATION OF FAILURE OF ELEVATING SCREWS ON 14" D. C. NO. 13 AND 14" D. C. NO. 14.

INTRODUCTION.

The elevating screws hereinafter described as No. 13 and No. 14 failed during the proof firing of the carriage to which they were attached. The description of the conditions under which the screws failed was submitted with the broken screws and very clearly showed that the failure was not a result of improper design but rather of defective material.

These screws were manufactured from purchased forgings. The chemical analysis of the heat from which these forgings were made was as follows:

C.	Mn.	Si.	P.	S.	Ni.	Cr.
0.430	0.643	0.190	0.030	0.018	3.06	1.07

The acceptance tests made at the works of the contractor are recorded below:

CARRIAGE NO. 13—93 INCHES LONG, 7¼ INCHES DIAMETER.

Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Fracture.
122,000	144,000	15.0	34.4	Silky

CARRIAGE NO. 14—93 INCHES LONG, 7¼ INCHES DIAMETER.

Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Fracture.
129,000	150,000	15.5	39.4	Silky.

CONCLUSIONS.

The conclusions given herein are based on facts developed in the course of this investigation and previous data derived from manufacturing experience at this arsenal.

The following suggestion presupposes the taking of longitudinal test specimens only to determine the suitability of the forging for threaded elevating screws requiring D steel.

1. Higher shock strength will be developed by placing the elastic limit between limiting values. Those suggested are 87,500 minimum,

100,000 maximum. The elongation requirement should be raised to 18 per cent and the contraction of area to 40 per cent.

2. The carbon content of the material should not exceed 0.45 per cent and the chromium not over 0.10 per cent. In other words, a straight nickel steel should be employed.

3. The following table gives the heat treatment and physical properties of a number of elevating screws recently manufactured at this arsenal. From this data it appears that a suitable treatment for developing a high shock strength in conjunction with an elastic limit of 87,000 to 100,000 pounds for D steel containing 3.50 per cent nickel with no chromium is as follows: Water quenching from 800° C., followed by tempering at 525° C. to 600° C.

The temperature will vary between the above limits, due to differences in hardness developed by the quenching operation or slight irregularities in the composition. If the quenching is done in oil, a hardening temperature some 50° higher should be used.

Marks on specimen.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch)	Elongation (per cent).	Contraction (per cent).	Charpy (foot-pounds per square inch).	Brinell hardness No.	Heat treatment.
7221 F5	92,000	115,500	21.0	57.2	255	255	Second treatment. Annealed 10 hours at 850° C. Quenched in water at 800° C. Drawn 4 hours at 580° C.
7228 F4	95,000	121,500	20.5	57.2	331	255	Fourth draw. Quenched in water at 800° C. Drawn 4 hours at 560° C.
7229 F	97,000	129,500	19.0	49.1	296	280	First treatment. Quenched in water at 800° C. Drawn 4 hours at 500° C.
7230 F3	94,000	119,500	21.0	59.8	354	255	Third draw. Quenched in water at 800° C. Drawn 4 hours at 540° C.
7231 F2	95,000	125,500	20.0	54.6	298	255	Second treatment. Quenched in water at 800° C. Drawn 3 hours at 540° C.
7232 F2	95,000	124,500	20.5	57.2	295	262	Second treatment. Quenched in water at 800° C. Drawn 4 hours at 525° C.
7233 F3	96,000	122,500	21.0	57.2	324	255	Third draw. Quenched in water at 800° C. Drawn 4 hours at 540° C.
7234 F2	92,000	122,000	21.0	57.2	329	255	Second treatment. Quenched in water at 800° C. Drawn 3 hours at 540° C.
7235 F2	92,000	121,500	22.0	57.2	334	248	Second treatment. Quenched in water at 800° C. Drawn 3 hours at 540° C.
7236 F	89,000	121,500	19.0	46.2	289	255	First treatment. Quenched in water at 800° C. Drawn 3¼ hours at 525° C.
7237 F5	96,000	119,000	22.5	57.2	265	241	Fifth treatment. Quenched in water at 800° C. Drawn 3 hours at 600° C.

Certain experimental evidence submitted herein makes it very apparent that threading a piece of material similar to a D steel elevating screw materially decreases its resistance to shock. The explanation of the deleterious effect of abrupt section changes in any section subjected to suddenly applied loads involves many points not clearly understood. Data have been presented in this report which show that the physical properties of the forging at right angles to the principal axis are very important and under present methods of inspection are not determined.

The advisability of introducing the transverse test for all forgings is questionable, but for those involving abrupt section changes such a test seems imperative. The more detailed discussion of this and related points is reserved to a later part of this report.

The following theory is presented, although discussed in detail later, to account for the behavior of the elevating screws in 14-inch D. C. carriages, model 1907, Nos. 13 and 14. This theory will at least serve to indicate the lines along which further investigation is now being conducted.

The two elevating screws examined were characterized by good ductility along the principal axis, and practically zero ductility at right angles to this direction. Being threaded, abrupt section changes are also present.

In service a severe stress is apparently applied along the major axis of the screw, good ductility being present in this direction. The principal stress wave upon encountering abrupt section changes sets up *extra stresses* (greater than Poissons ratio?) at right angles to the principal axis. No ductility being present in this direction failure results.

EXPERIMENTAL.

The general plan followed in this investigation was to determine by a variety of physical tests and by microscopical examination the nature of the metal in the screws, and to see if the composition employed in the fabrication of the forgings would not yield to a suitable treatment, so that more satisfactory properties would be developed. Experiments were also conducted on threaded specimens to show, if possible, the influence of threading on such material when stresses are applied suddenly.

To assist in the presentation of the data, the fractured specimens from screw 4545, carriage No. 13, have been photographed and the results inserted below each photograph, together with the necessary descriptive remarks.

DESCRIPTION OF TESTS.

The following details are presented at this point, so that the terms used hereafter will be clearly understood.

Static tensile test: Standard test specimen 0.505 inches diameter. (See drawing on p. 49.)

The load was applied in increments of 5,000 or 10,000 pounds until the stress reached 60,000 or 70,000 pounds, after which the loading increment was reduced to 1,000 pounds until the elastic limit was passed. These results were plotted and the yield point and elastic limit determined from the stress-strain diagram. The yield point was determined as the point where the stress-strain curve departed 0.0004 inch from the Hooks's Law curve. This procedure was adopted as it was thought that this point would correspond to that generally reported as the elastic limit. The stress-strain curve very appreciably flattens above this point. The elastic limit was determined as the point where the elongation and load ceased to be directly proportional.

CHARPY NOTCHED BAR TRANSVERSE TEST.

A drawing of this specimen is shown on page 49. This test consists of an impact transverse test on the notched square bar.

CHARPY NOTCHED BAR TENSILE TEST.

A drawing of this specimen is shown on page 49. This test consists of an impact tensile test on a grooved tensile specimen.

CHARPY TENSILE TEST.

A drawing of this specimen is shown on page 49. This test consists of an impact tensile test on a uniform section tensile specimen.

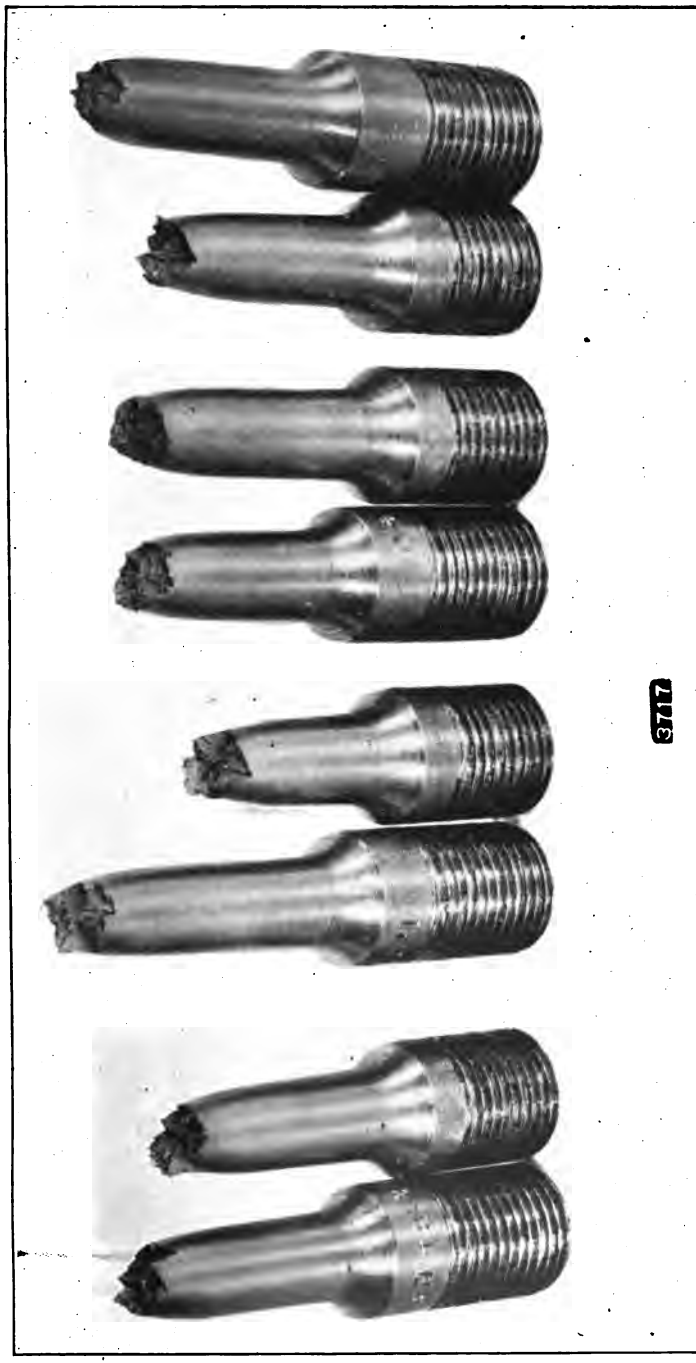
MATERIAL.

Elevating screw from carriage No. 13, as received from service.

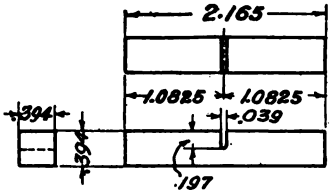
Static tensile test.—Tensile specimens tested in Emery hydraulic machine. Specimens shown above were taken in direction of axis of screw, or, in other words, they were longitudinal specimens. Tensile tests under present specifications would be taken as above.

Results.

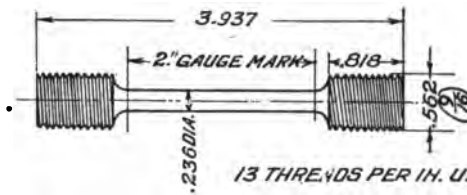
Specimen marks.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
1	108,000	112,000	137,000	19.0	51.9	293
2	108,000	111,000	136,500	19.0	51.9	281
3	100,000	107,000	136,000	19.0	49.1	277
4	100,000	109,000	136,500	19.5	51.9	281
Mean	104,000	109,750	136,500	19.2	51.2	283



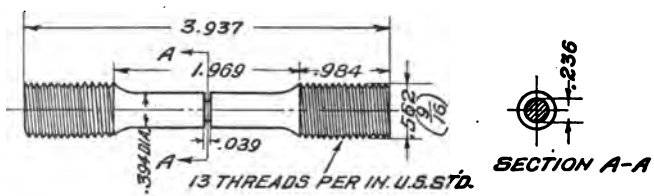
31082°—18——4



CHARPY NOTCHED BAR FOR TRANSVERSE TEST



CHARPY BAR FOR TENSILE TEST



CHARPY NOTCHED BAR FOR TENSILE TEST.

BOTH ENDS OF BARS TO BE STAMPED WITH NUMBER OF TEST PIECE.

CHARPY BARS.

MATERIAL.

Elevating screw from carriage No. 13, as received from service.

Static tensile test.—Tensile specimens tested in Emery hydraulic machine. Specimens shown above were taken at right angles to axis of screw, or, in other words, *transverse* specimens.

Results.

Specimen marks.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
1	.....	[1] 107,000	116,500	2.5	5.7	285
2	85,000	99,000	121,500	3.5	5.7	277
3	85,000	95,000	120,000	4.0	5.7	277
Mean	85,000	97,000	119,350	3.3	5.7	280

[1] Extensometer readings not taken. Result not used in computing mean.

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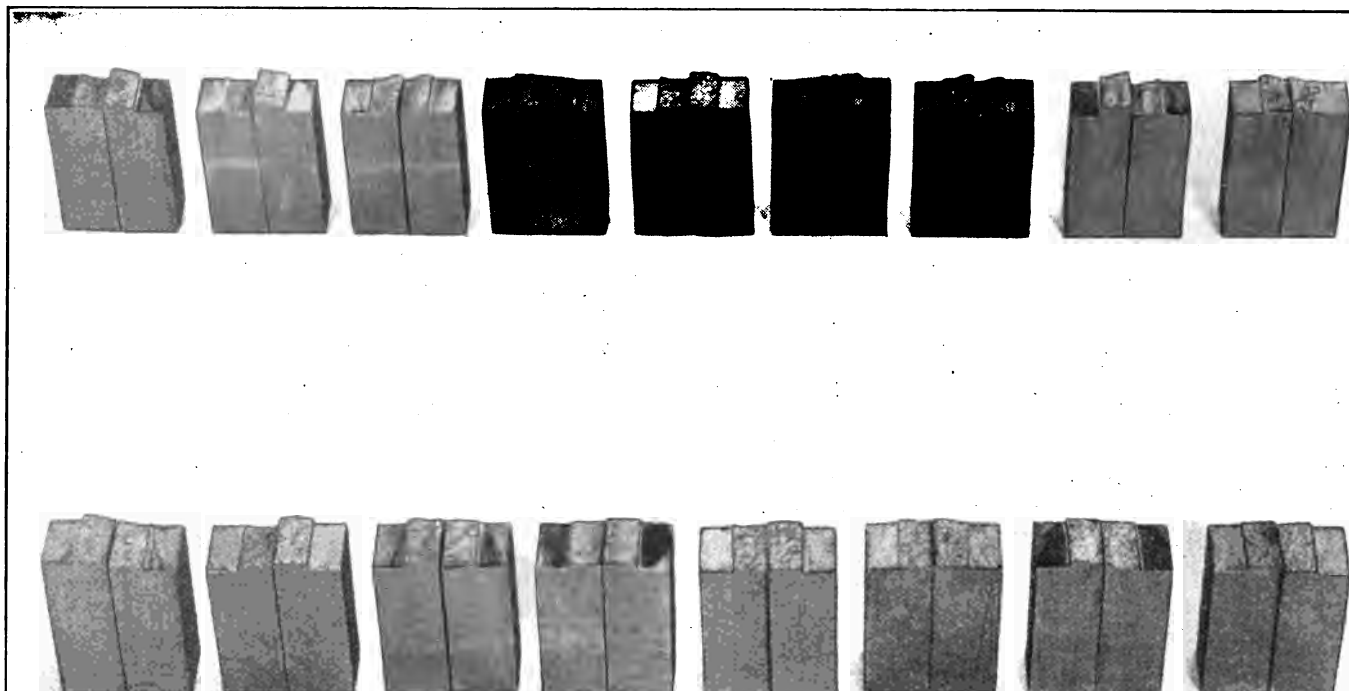

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MATERIAL.

Elevating screw from carriage No. 13, as received from service.

Charpy notched bar transverse test.—Lower row taken at right angles to axis of screw with slot cut in direction of axis (*transverse Charpy*); upper row taken in direction of axis of screw with slot cut at right angles to axis (*longitudinal Charpy*).

Results.

Transverse.		Longitudinal.	
No.	Foot-pounds per square inch.	No.	Foot-pounds per square inch.
1	17.1	1	26.8
2	21.7	2	26.8
3	20.6	3	27.9
4	16.0	4	19.4
5	21.8	5	25.5
6	12.4	6	27.9
7	18.3	7	39.1
8	12.4	8	26.8
		9	26.8
Mean	17.5	Mean	27.4

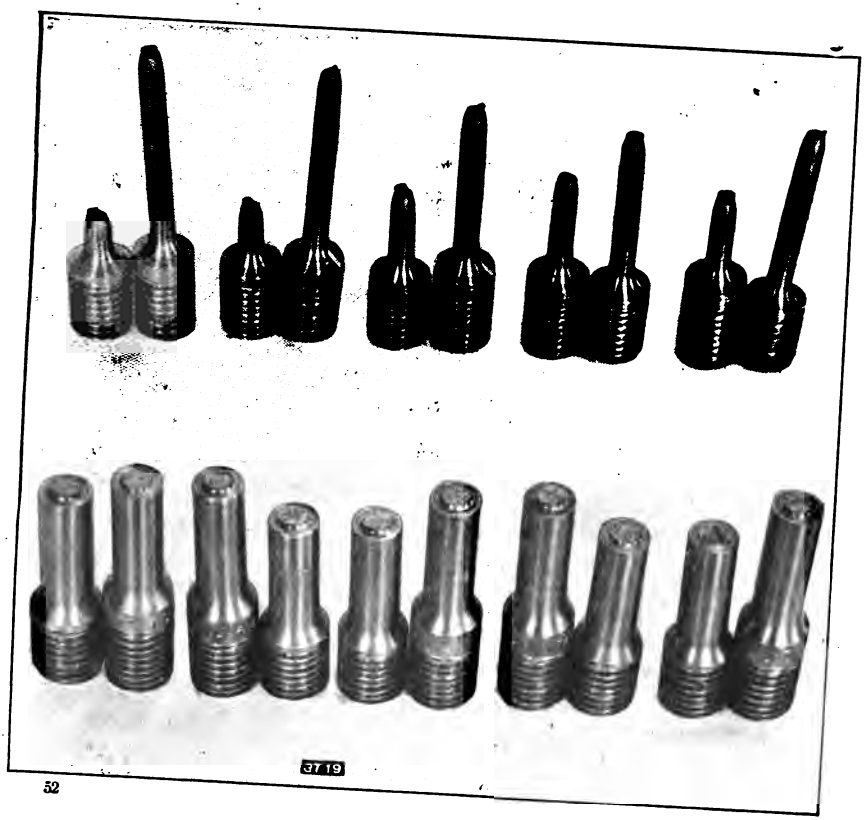
MATERIAL.

Elevating screw from carriage No. 13, as received from service.

Tensile Charpy specimens taken along axis of screw (*longitudinal*). Upper row not notched; lower row notched with a diameter at bottom of notch equal to diameter of unnotched specimen.

Results.

Specimens not notched.					Notched specimens.		
No.	Diameter (inches).	Foot-pounds per square inch.	Elongation in 2 inches (per cent).	Contraction of area (per cent).	No.	Diameter (inches).	Foot-pounds per square inch.
1	0.237	3,340	13.5	54.5	1	0.233	76
2	.237	4,060	16.0	56.8	2	.235	128
3	.237	3,650	15.0	56.8	3	.239	141
4	.237	4,030	16.5	56.8	4	.237	138
5	.237	3,740	15.0	59.0	5	.239	187
Mean		3,760	15.2	56.8	Mean		134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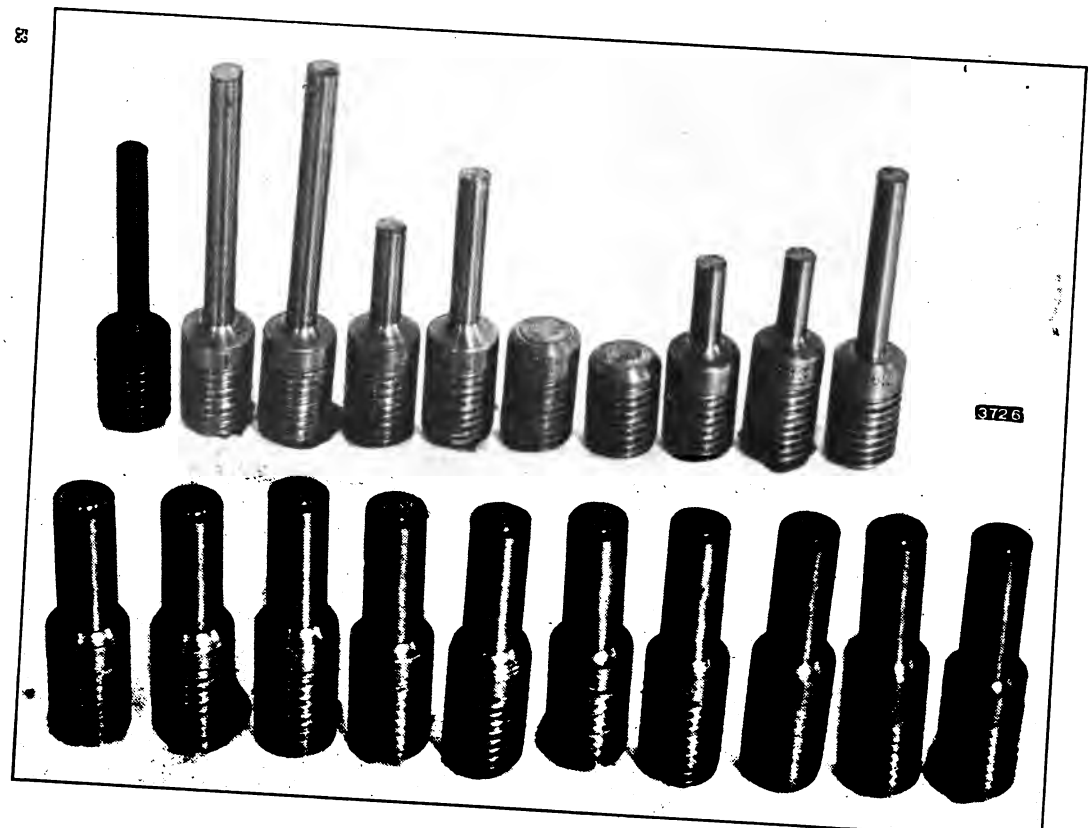
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MATERIAL.

Elevating screw from carriage No. 13, as received from service.

Tensile Charpy specimens, taken at right angles to axis of elevating screw. Upper row not notched; lower row notched, with a diameter at bottom of notch equal to diameter of unnotched specimen.

Results.

Specimens not notched.				Notched specimens.		
No.	Diameter (inches).	Foot-pounds per square inch.	Elongation (per cent).	No.	Diameter (inches).	Foot-pounds per square inch.
1	0.237	[1] 19.9	0.5	1	0.238	32.2
2	.237	129.0	1.0	2	.237	56.0
3	.237	[1] 85.0	.5	3	.237	62.5
4	.238	149.0	1.0	4	.239	46.6
5	.237	109.0	.5	5	.235	30.9
Mean		129.0	.8	Mean		45.6

[1] Results not used in computing mean.

MATERIAL.

Elevating screw from carriage No. 13 as received from service.

Static tests.—Specimens pulled in Emery hydraulic machine (*miniature elevating screws*). These specimens were made as nearly proportional as possible to the elevating screw.

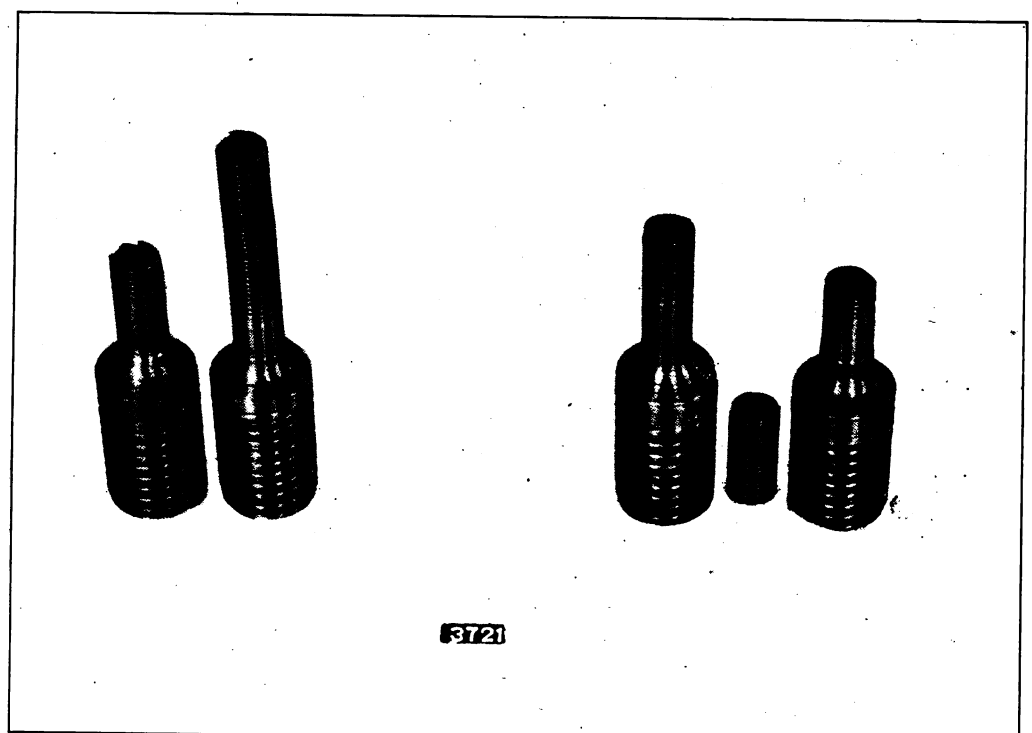
The two specimens on the left were taken in direction of axis of elevating screw (longitudinal).

The two specimens on the right were taken at right angles to axis of elevating screw (transverse).

Results.

LONGITUDINAL MINIATURE SCREWS.					TRANSVERSE MINIATURE SCREWS.				
Specimen.	Flastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Specimen.	Flastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent.)	Contraction of area (per cent).
1.....	117,750	146,650	5.5	31.1	1.....	113,350	124,450	1.5	None.
2.....	120,000	151,100	8.0	24.4	2.....	113,350	135,550	2.5	None.
Mean..	118,875	148,875	6.7	27.7	Mean..	113,350	130,000	2.0	None.

3723



3721

MATERIAL.

Elevating screw from carriage No. 13 as received from service.

Charpy tensile test on miniature elevating screws. Both specimens taken in direction of axis of elevating screw.

Results.

Specimen No.	Diameter (inches).	Foot-pounds per square inch.	Elongation in 2 inches (per cent).
1	0.240	512	2.5
2	.240	382	1.5
Mean	.240	447	2.0

MATERIAL.

Elevating screw from carriage No. 13 as received from service.

Miniature elevating screws broken in Charpy machine. The design of the thread was the same on the two specimens on the left as now used on the elevating screw. The thread was changed on the two specimens on the right and rounded at the base. The sketch below illustrates the conditions present.

Results.

Description of specimen.	Diameter (inches).	Foot-pounds per square inch.	Elongation in 2 inches (per cent).	Mean foot-pounds per square inch.
Flat bottom thread	0.340	576	1.5	735
Do	.340	895	3.0	.....
Round bottom thread	.340	137	1.0	347
Do	.340	558	1.5	.....

MATERIAL.

Elevating screw from carriage No. 13 as received from service.

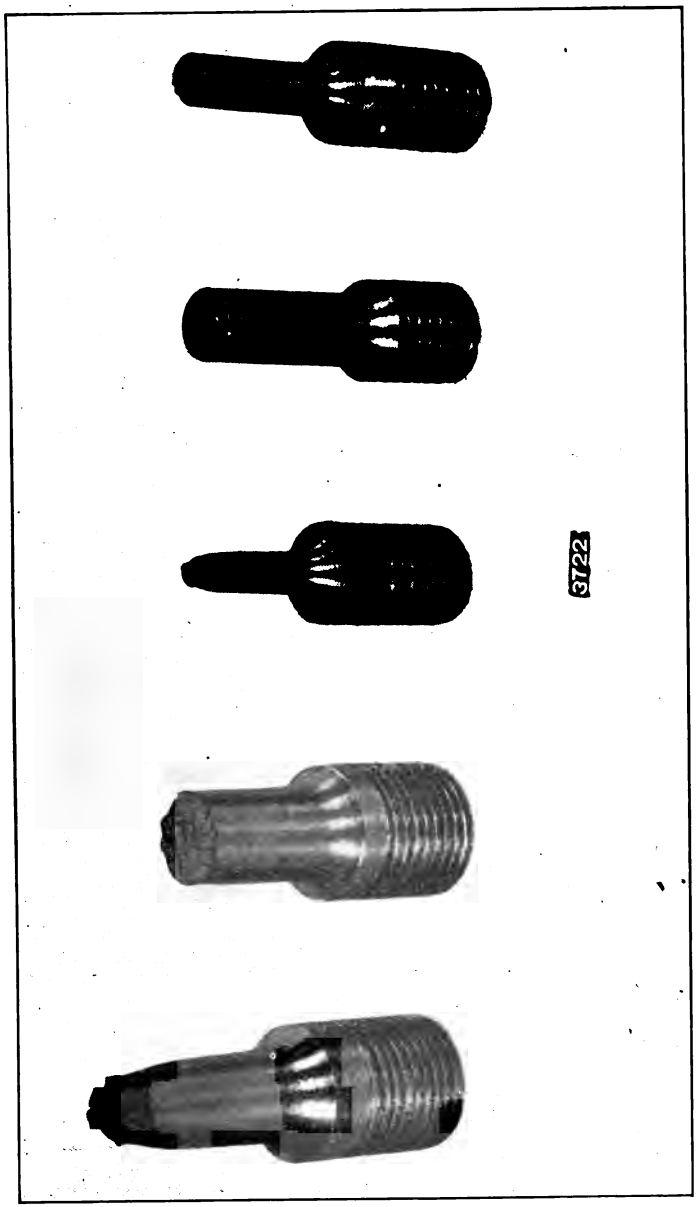
From left to right the first specimen shows fractured end of static tensile specimen taken in longitudinal direction. Good ductility, elastic limit, and tensile strength.

The second represents a static tensile specimen taken at right angles to number one, or, in other words, a transverse specimen. No ductility, good elastic limit, and tensile strength.

Specimen No. 3 represents an unnotched longitudinal Charpy specimen. High shock strength, good ductility.

Specimen No. 4 represents a notched longitudinal Charpy specimen. Low shock strength.

Specimen No. 5 represents a miniature elevating screw taken in a longitudinal direction and broken as a tensile specimen in Charpy machine. Low shock strength.



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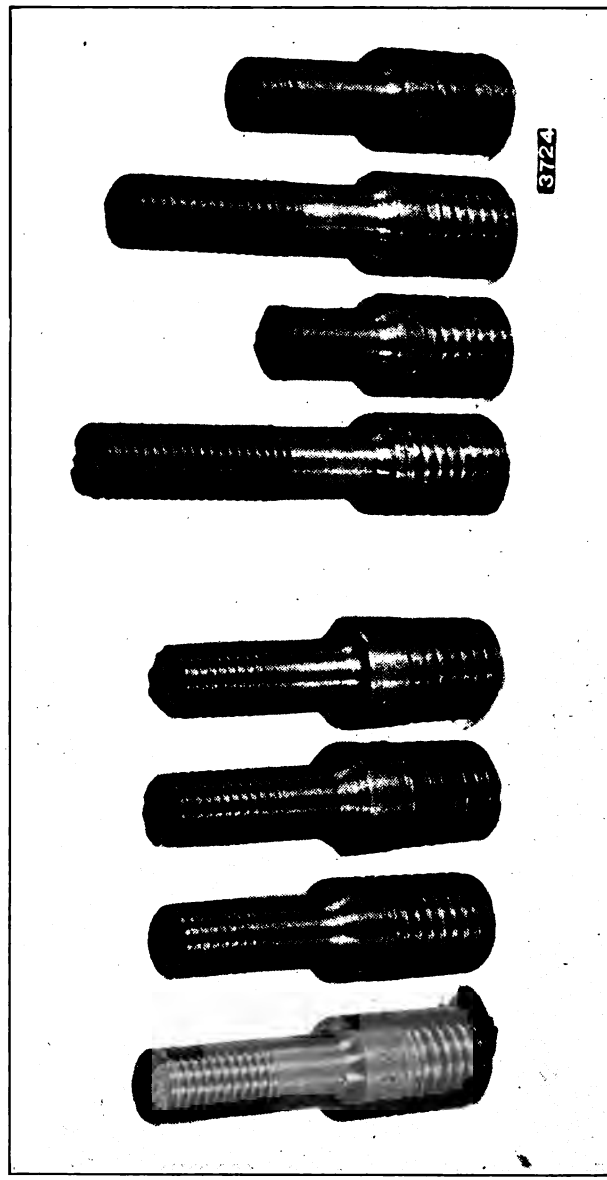

3724

Summary of results on screw 4545, carriage No. 13, as received from service.

Nature of test.	Description of specimen.	Yield point (pounds per square inch).	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Foot-pounds absorbed per square inch.
Static tensile (mean of 4 tests).	0.505-inch standard tensile (longitudinal).	109,750	104,000	136,500	19.2	51.2	.....
Static tensile (mean of 3 tests).	0.505-inch standard tensile (transverse).	97,000	85,000	119,350	3.3	5.7	.....
Charpy notched bar, transverse test (mean of 8 tests).	Notched bar (longitudinal).	.....	.....	.....	.....	.....	27.4
Charpy notched bar, transverse test (mean of 8 tests).	Notched bar (transverse).	.....	.....	.....	.....	.....	17.5
Charpy tensile test (mean of 5 tests).	Small tensile bar without notch, 0.237 inch diameter (longitudinal).	.....	.....	.....	15.2	56.8	3,760
Charpy notched bar, tensile test (mean of 5 tests).	Small tensile bar with notch, 0.237 inch at bottom (longitudinal).	.....	.....	.....	.....	.....	134
Charpy tensile test (mean of 5 tests).	Small tensile bar without notch, 0.237 inch diameter (transverse).	.....	.....	.....	.8	.....	129
Charpy notched bar, tensile test (mean of 5 tests).	Small tensile bar with notch. 0.237 inch diameter (transverse).	.....	.....	.....	.....	.....	45.6

Miniature elevating screws.

Nature of test.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Foot-pounds absorbed per square inch.
Static longitudinal (mean of 2 tests).....	118,875	148,875	6.7	27.7	.....
Static transverse (mean of 2 tests).....	113,350	130,000	2.0	None.	.....
Charpy traction test (longitudinal; mean of 2 tests).....	.....	.....	.....	.....	447
Charpy traction test (longitudinal); diameter at bottom of thread, 0.340 inch; flat bottom thread.....	.....	.....	.....	.....	735
Charpy traction test (longitudinal); diameter at bottom of thread, 0.340 inch; round bottom thread.....	.....	.....	.....	.....	347

An examination of these physical tests enables the statement of several facts.

(1) The longitudinal static tensile specimens show good physical qualities, meeting the specifications for forged steel D. The yield point and elastic limit are only separated by 5,750 pounds.

(2) The transverse static tensile specimens show a lower elastic limit and ultimate strength than the longitudinal tensile specimens, but are particularly marked by the absence of ductility. The yield point and tensile strength differ by 12,000 pounds.

(3) The Charpy strength as determined by the notched bar specimens is very low, being comparable to a good cast iron. Elevating screws recently manufactured have a Charpy strength of 300 to 350,

or, using this test as a criterion of shock-resisting power, over 10 times as great. The specimens taken in a longitudinal direction gave approximately 60 per cent greater resistance than the transverse specimens.

(4) The small Charpy tensile bars taken longitudinally gave 3,760 foot-pounds. The diameter of these specimens was 0.237 inch. The small tensile bars with notch, the diameter of the base of the notch being 0.237 inch, gave 134 foot-pounds. The very apparent fact is that the notch seriously reduced the shock strength, the notched bars offering one twenty-eighth of the resistance of the unnotched specimens. Neglecting the merits and demerits of the respective specimens, it can be stated that abrupt change of section acts in some very pronounced manner to reduce the resistance to shock.

(5) The small unnotched Charpy tensile specimens taken in a transverse direction gave a mean value of 129 foot-pounds, whereas the notched tensile specimens taken in the same direction gave 45.6 foot-pounds, or a reduction of approximately one-third. The difference between the notched and unnotched specimens was much less when the specimens were taken in the transverse direction. It is to be noted in this connection that the ductility was good in the longitudinal direction, but practically zero in the transverse direction. It would seem that a very close relation exists between ductility and the effect of abrupt section changes.

(6) It is also of interest to note that the longitudinal specimens notched gave a mean value of 134 foot-pounds, whereas the unnotched transverse specimens gave 129 foot-pounds. A pertinent question can be raised at this point, namely, Does abrupt section change make the stresses at right angles to the axis of the specimen greater than Poisson's ratio (generally accepted as one-third) of the principal stress when the stress is suddenly applied?

(7) As the influence of the notch on specimens subjected to shock was so apparent, a number of miniature elevating screws were made. These miniature screws had dimensions proportional to the service screw.

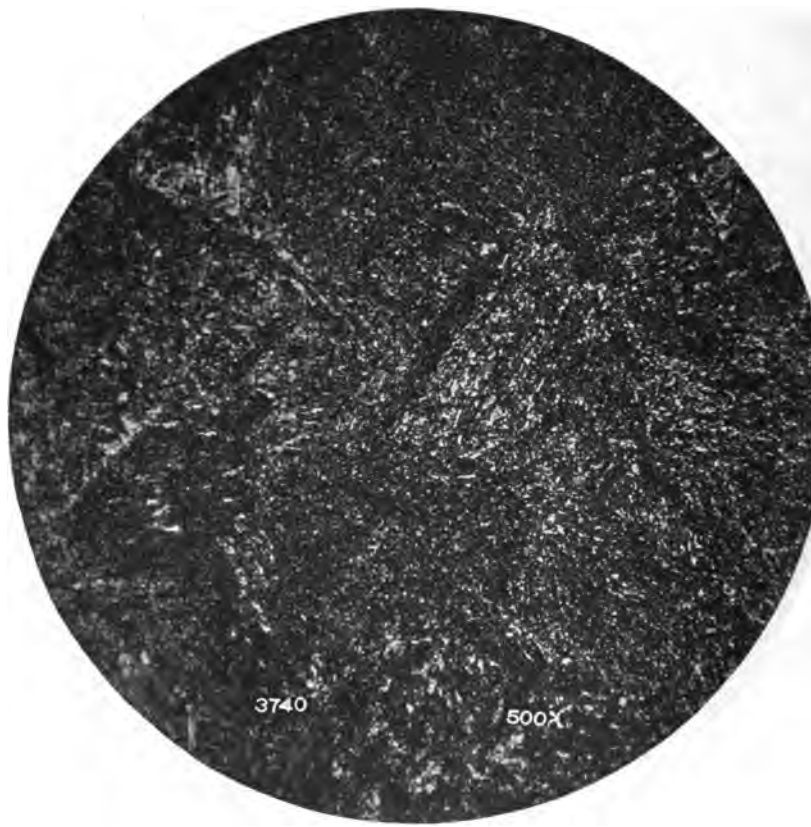
Static tensile tests on these screws showed that the yield and tensile strength were increased by the presence of the threads, whereas the ductility was reduced. This is true for both longitudinal and transverse specimens, and is in agreement with our present knowledge that a notch or thread will increase the yield point and tensile strength on the reduced section caused by notching or threading.

(8) Miniature elevating screws were then taken in a longitudinal direction to approximate service conditions. The foot-pounds absorbed in the rupture of these specimens gave a mean value of 447.

	Foot-pounds.
Unnotched bar, 0.237 inch	3,760
Notched bar, 0.237 inch base of notch	134
Miniature elevating screw, 0.237 inch base of thread	447

The notch in the notched bar specimen was continuous, whereas in the threaded screw the fracture must pass through a thread or over a greater area than is the case with the regular notched Charpy tensile specimen. These results show beyond doubt that threading has served to bring into play the factors associated with abrupt change of section, and it is reasonable to assume that these factors are active

Micrograph No. 3727 at 500 diameters shows the general structure of screws broken in carr.ages Nos. 13 and 14. The original martensitic formation caused by quenching still persists, which is in itself an indication of brittleness, and the presence of such a structure would have been sufficient grounds for recommending retreatment.



Micrograph No. 3740 at 500 diameters shows the structure of screw No. 13 after the 650° tempering operation. The structure is distinctly sorbitic. A comparison of this microstructure with that of the screw as received will show at a glance the decided improvement brought about by a higher drawing temperature.

under service conditions, as the fractures of the elevating screws which failed in service were very similar to the fracture of the miniature elevating screw broken in the Charpy machine. Furthermore, no ductility was displayed by either after rupture, which shows conclusively that the properties exhibited by the longitudinal static tensile specimen were not utilized previous to failure.

(9) The ordinary tensile tests showed a complete lack of ductility at right angles to the axis of the screw. (See pp. 50–56.) Our present knowledge would, therefore, lead us to conclude that brittleness would be experienced at right angles to the principal axis. The unnotched Charpy tensile specimens, taken at right angles to the axis of the screw, verify this conclusion. (See p. 53.) The apparent effect of notching a bar taken in the longitudinal direction is to weaken it under shock. It is assumed that the effect of the notch is to seriously augment the stresses at right angles to the main axis of the screw (see p. 52), and as brittleness is present in this direction, failure occurs at unexpectedly low stresses.

The following results were obtained from the elevating screw which failed in carriage No. 14, and an inspection of these figures, together with a comparison with the results on the screw from carriage No. 13, enable the following conclusions to be drawn:

Static tensile test.

LONGITUDINAL SPECIMEN.

Specimen mark.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
1	110,000	114,000	140,000	16.5	46.2	285
2	105,000	114,000	140,500	16.0	46.2	285
3	100,000	111,000	139,000	17.5	46.2	285
4	104,000	109,000	138,000	17.5	46.2	285
Mean	104,750	112,000	139,250	16.9	46.2	285

TRANSVERSE SECTION.

1	92,000	99,000	108,542	1.5	5.5	285
2	92,000	100,000	110,000	1.5	5.7	262
3	95,000	100,000	114,500	1.5	5.7	285
Mean	93,000	99,666	111,014	1.5	5.6	277

Charpy notched bar transverse test.

Specimens taken longitudinally (foot-pounds absorbed per square inch).	Specimens taken transversely (foot-pounds absorbed per square inch).
26.7	8.9
20.6	25.3
25.5	15.9
26.7	10.1
26.7	14.8
20.6	17.0
25.5	14.7
26.7	13.5
Mean— 24.9	Mean— 15.0

Charpy notched bar tensile test.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.
1	138.0
2	172.0
3	85.1
4	139.0
5	87.3
Mean	124.2

Charpy tensile test on unnotched bars.—Diameter of bars equal to diameter at bottom of notch of notched Charpy tensile specimens.

LONGITUDINAL.

Specimen.	Foot-pounds absorbed per square inch.	Elongation (per cent).	Contraction of area (per cent).
1	1,680	[1] 5.5	.....
2	3,580	13.5	50.0
3	3,610	14.0	52.2
4	600	[1] 1.5	.....
5	2,850	9.5	.....
Mean	3,347	.....	.....

[1] Fractured at fillet. These specimens are omitted from the mean as they fractured without contraction of area, the fracture being caused by improper radius of fillet.

Charpy notched bar tensile test.

TRANSVERSE.

Specimen.	Foot-pounds per square inch.
1	50.2
2	58.8
3	63.0
4	48.6
5	46.7
Mean	53.4

Charpy tensile test on unnotched bars.—Diameter of bars equal to diameter at bottom of notch.

TRANSVERSE.

Specimen.	Foot-pounds absorbed per square inch.	Elongation (per cent).	Contraction of area (per cent).
1	344.0	1.5	2.2
2	127.0	1.0	2.2
3	93.8	1.0	2.2
4	138.0	1.0	2.2
5	114.0	1.0	2.2
Mean	163.3	1.1	2.2

Micrograph No. 3739, taken at 500 diameters, from the material of the screw after quenching and drawing at 575° C. shows a very fine structure consisting of sorbite and troostite. The faint outlines of large grains are visible. This network could not have resulted from the heating for quenching as the temperature was too low. It is probably the result of some earlier treatment, the results of which were not obliterated entirely by the subsequent heating above the range.

1. The static tensile qualities of No. 14 are very similar to No. 13. The former has a slightly lower yield point and tensile strength and higher elongation and contraction in the longitudinal direction. Both sets of transverse specimens were marked with very low ductility.

2. The Charpy notched bar transverse tensile test gave almost identical results on the two screws.

3. The results of the Charpy notched bar tensile test were nearly alike for the specimens taken in a longitudinal direction, and for those taken in the transverse direction the specimens from screw No. 14 gave inferior results, approximately 50 per cent of strength shown by the specimens from screw No. 13.

4. The Charpy tensile specimens without notches agreed very closely both for the longitudinal and transverse direction. The Charpy notched bar tensile tests for screw No. 14 taken in the longitudinal direction gave a mean of 125 foot-pounds, whereas the Charpy tensile specimens without a notch taken in the transverse direction gave 163.3. Here again is evidence that notching the longitudinal test specimen brings into play the properties exhibited by the transverse unnotched specimen.

The results of the tests on the two screws were in such good agreement and as they apparently suffered from the same defects, No. 13 only was selected for further work.

This additional investigation consisted in heat treating a section of the elevating screw from carriage No. 13 and determining its physical properties by a series of tests similar to those already described. The heat treatment consisted in heating one of the broken sections of screw No. 13 about 2 feet in length to 800° C., followed by quenching in water. After quenching in water the piece was tempered 4 hours at 575° C. One half of this section was cut up for test and the remaining piece tempered two additional hours at 650° C.

MATERIAL.

Screw No. 13, heated to 800° C., quenched in water, and drawn four hours at 575°.

Static tensile test.—Top row shows longitudinal specimens and bottom row shows transverse specimens.

LONGITUDINAL.

Specimen.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
1	105,000	110,000	135,500	19.0	49.1	285
2	105,000	110,000	136,500	17.0	49.1	285
3	105,000	109,000	135,500	18.5	46.2	269
Mean	105,000	109,666	135,833	18.2	48.1	279

TRANSVERSE.

1	100,000	105,000	.....	3.5	.....	277
2	100,000	104,000	129,500	6.5	13.3	277
3	100,000	105,000	131,000	9.0	9.5	269
Mean	100,000	104,666	130,250	6.3	7.6	274

MATERIAL.

Screw heated to 800° C., quenched in water, and drawn four hours at 575° C.

Charpy tensile test.—Top row shows longitudinal tests and bottom row shows transverse tests.

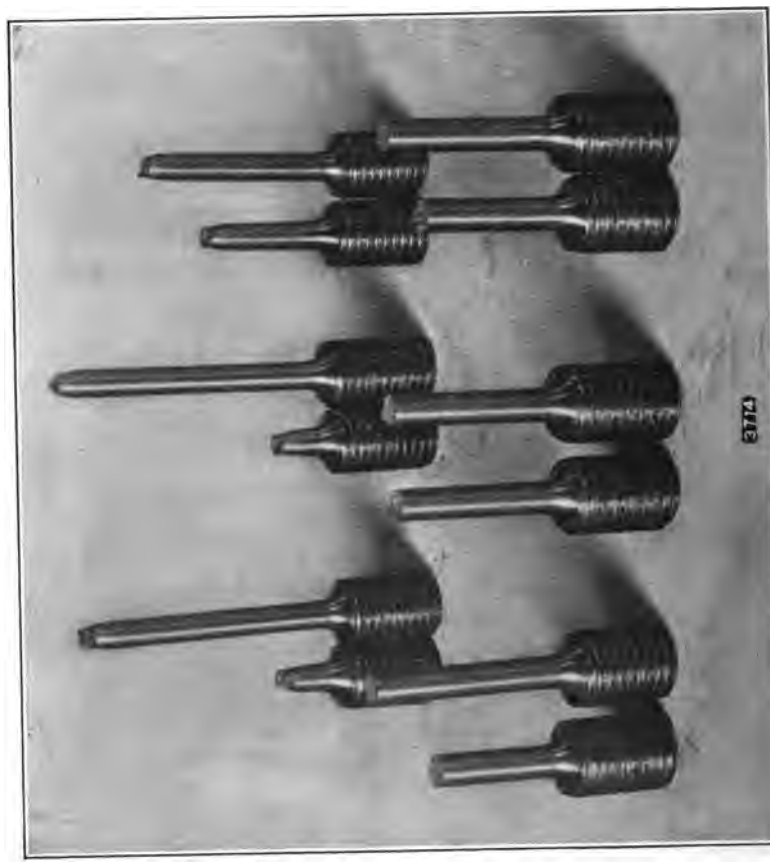
LONGITUDINAL.

Specimen.	Foot-pounds absorbed per square inch.	Elongation (per cent).	Contraction (per cent).
1	2,990	16.0	50.0
2	3,670	14.5	54.5
3	4,180	16.5	56.8
Mean	3,940	15.6	53.7

TRANSVERSE.

1	1,480	7.0	9.0
2	2,640	10.5	18.1
3	1,140	5.0	6.8
Mean	1,750	7.5	11.3

62-1



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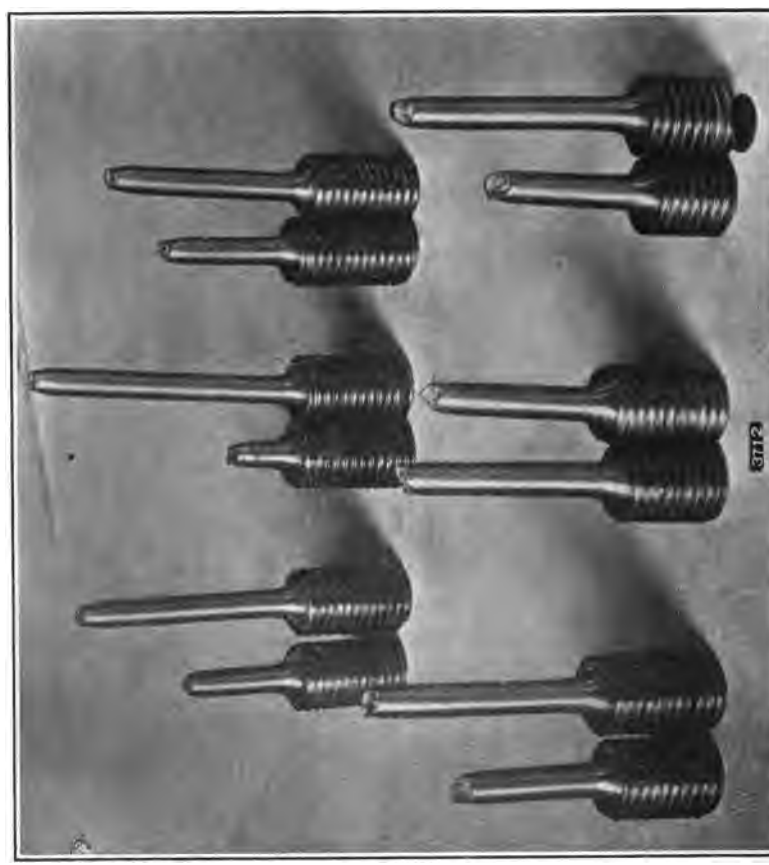
63–1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MATERIAL.

Screw heated to 800° C., quenched in water, and drawn four hours at 575° C.

Charpy notched bar transverse test.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.
1	41.3
2	27.8
3	32.8
4	41.4
Mean	35.8

TRANSVERSE.

1	26.6
2	25.5
3	38.8
4	26.6
Mean	29.4

Charpy notched bar tensile test.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.
1	293
2	233
3	277
Mean	269

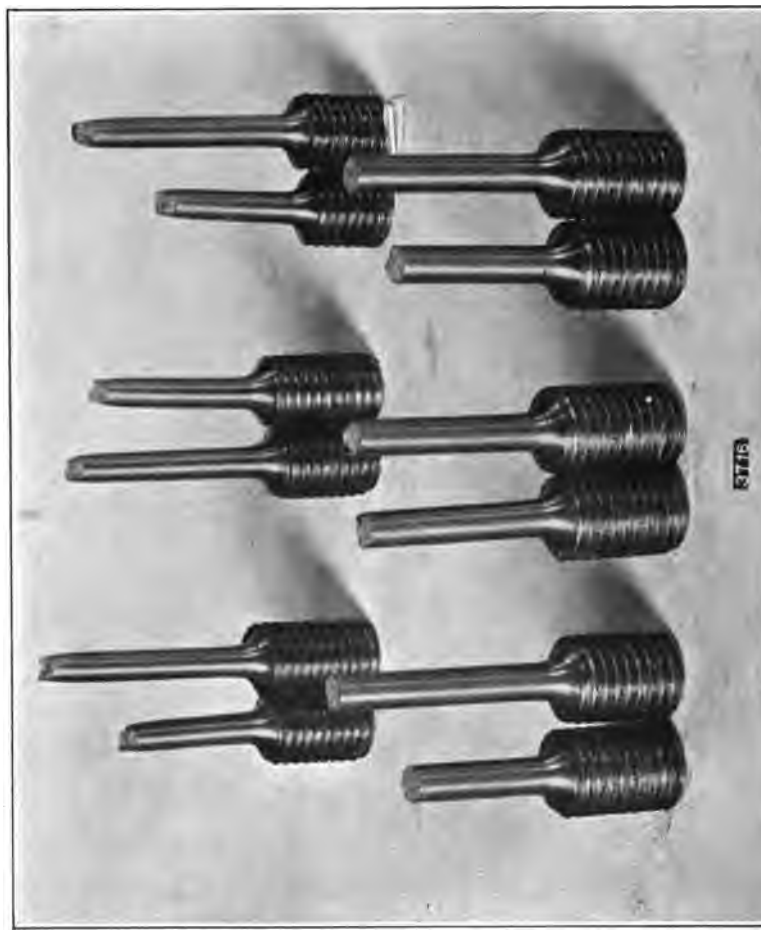
TRANSVERSE.

Specimen.	Foot-pounds per square inch.
1	66.2
2	45.8
3	162.0
Mean	91.3

Summary of tests on elevating screw from carriage No. 13 after quenching in water from 800° C. and drawing four hours at 575° C.

Nature of test.	Description of specimen.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Foot-pounds absorbed per square inch.
Static tensile (mean of 3 tests).	0.505 inch diameter (longitudinal).	105,000	109,666	135,833	18.2	48.1	.....
Static tensile (mean of 3 tests).	0.505 inch diameter (transverse).	100,000	104,666	130,250	6.3	7.6	.....
Charpy notched bar, transverse test (mean of 4 tests).	Bars taken in longitudinal direction.	.....	.....	.....	.....	.....	35.8
Charpy notched bar, transverse test (mean of 4 tests).	Bars taken in transverse direction.	.....	.....	.....	.....	.....	29.4
Charpy tensile test (mean of 3 tests).	0.237 inch diameter (longitudinal).	.....	.....	.....	15.6	53.7	3,940
Charpy tensile test (mean of 3 tests).	0.237 inch diameter (transverse).	.....	.....	.....	7.5	11.3	1,750
Charpy notched bar, tensile test (mean of 3 tests).	0.237 inch diameter at bottom of notch (longitudinal).	.....	.....	.....	.....	.....	269
Charpy notched bar, tensile test (mean of 3 tests).	0.237 inch diameter at bottom of notch (transverse).	.....	.....	.....	.....	.....	91.2

65–1



MATERIAL.

Screw heated to 800° C., quenched in water, drawn 4 hours at 575° C. and 2 additional hours at 650° C.

Static test.—Top row shows specimens taken in longitudinal direction. Bottom row shows transverse specimens.

LONGITUDINAL.

Specimen marks.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness No.
1	94,000	98,000	122,000	20.0	54.6	255
2	93,000	96,000	120,500	21.0	54.6	248
3	92,000	95,000	120,000	21.0	54.6	248
Mean	93,000	96,333	120,833	20.6	54.6	250

TRANSVERSE.

1	90,000	93,000	113,500	16.5	34.0	241
2	93,000	95,000	119,500	16.0	34.0	241
3	93,000	96,000	120,500	14.5	34.0	248
Mean	92,000	94,666	119,500	15.6	34.0	243

MATERIAL.

Screw heated to 800° C. and quenched in water, drawn 4 hours at 575° C. and 2 additional hours at 650° C.

Tensile charpy test.—Top row shows longitudinal specimens. Bottom row shows transverse specimens.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.	Elongation (per cent).	Contraction (per cent).
1	4,140	18.0	56.8
2	4,010	18.0	56.8
3	3,750	16.5	59.0
Mean	3,960	17.5	57.5

TRANSVERSE.

1	3,730	16.0	40.9
2	4,020	17.5	43.1
3	3,810	16.0	40.9
Mean	3,850	16.5	41.6

MATERIAL.

Screw quenched in water from 800° C. and drawn 4 hours at 575° C., followed by 2 hours at 650° C.

Charpy notched bar transverse test.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.
1	143
2	126
3	141
4	153
Mean	141

TRANSVERSE.

1	29.1
2	64.5
3	73.8
4	65.8
Mean	58.3

Charpy tensile notched bar test.

LONGITUDINAL.

Specimen.	Foot-pounds per square inch.
1	312
2	391
3	250
Mean	318

TRANSVERSE.

1	187
2	147
3	161
Mean	165

Comparison of transverse static tests after quenching at 800° C. in water and tempering at 575° C. and 650° C., respectively. Bottom row tempered at 575° C. Top row tempered at 650° C.

Mean results.

Specimen	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
Drawn at 575° C	100,000	104,666	130,250	6.3	7.6	274
Drawn at 650° C	93,000	94,666	119,500	15.6	34.0	243

Comparison of transverse Charpy tensile tests after quenching at 800° C. in water and tempering at 575° C. and 650° C., respectively. Bottom row tempered at 575° C. Top row tempered at 650° C.

Mean results.

Specimen	Foot-pounds per square inch.	Elongation (per cent).	Contraction of area (per cent).
Drawn at 575° C.	1,750	7.5	11.3
Drawn at 650° C.	3,850	16.5	41.6

Summary of tests on elevating screw from carriage No. 13 after quenching in water from 800° C., drawing 4 hours at 575° C., and 2 hours at 650° C.

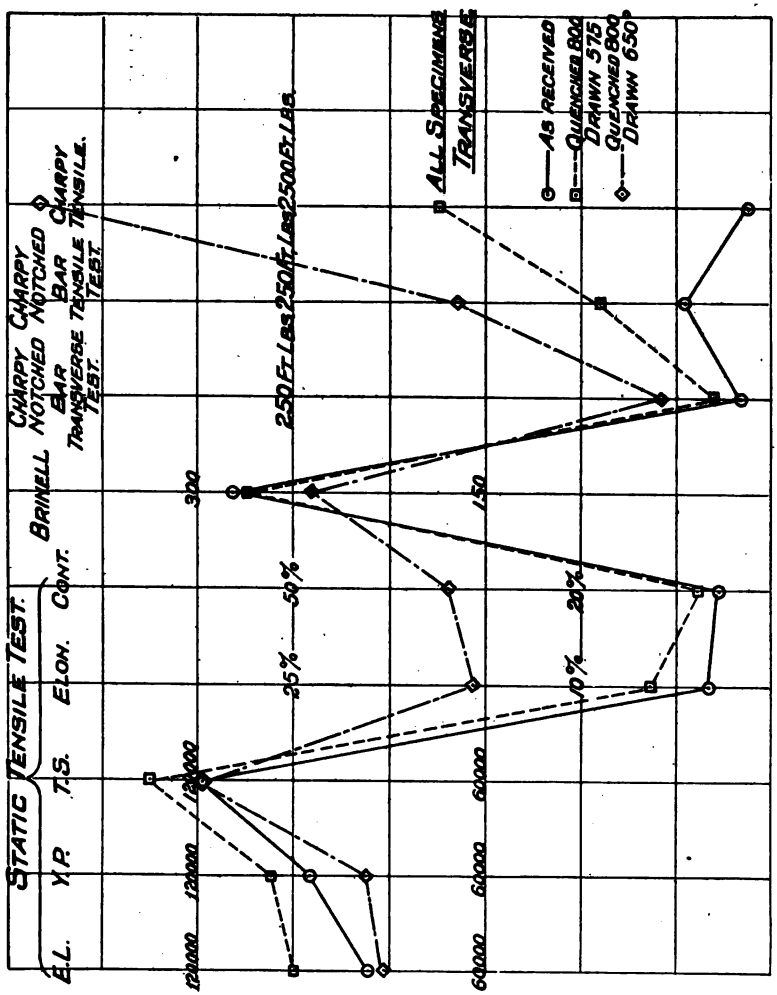
Nature of test.	Description of specimen.	Elastic limit (pounds per square inch).	Yield point (pounds per square inch).	Tensile strength (foot-pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Foot-pounds absorbed per square inch.
Static tensile (mean of 3 tests).	0.505 inch diameter (longitudinal).	93,000	96,333	120,833	20.6	54.6	.....
Do	0.505 inch diameter (transverse).	92,000	94,666	119,500	16.6	34.0	.....
Charpy notched bar transverse test (mean of 4 tests).	Bars taken in longitudinal direction.	.....	.....	.....	.....	.....	141
Do	Bars taken in transverse direction.	.....	.....	.....	.....	.....	58.3
Charpy tensile test (mean of 3 tests).	0.237 inch diameter (longitudinal).	.....	.....	.....	17.5	57.5	3,960
Do	0.237 inch diameter transverse	.....	.....	.....	15.5	41.6	3,850
Charpy notched bar tensile test (mean of 3 tests).	0.237 inch diameter at bottom of notch (longitudinal).	.....	.....	.....	.....	.....	318
Do	0.237 inch diameter at bottom of notch (transverse).	.....	.....	.....	.....	.....	165

On the following page the results of the tests taken in a longitudinal direction are shown graphically. Values obtained for any particular test are represented by the ordinates. Three series of tests are shown: (1) Longitudinal tests on screw No. 13 as received from service marked ⊙; (2) longitudinal tests on screw No. 13 after re-treatment consisting in water quenching from 800° C. followed by tempering at 575° C. for 4 hours, marked ⊡; (3) longitudinal tests on screw No. 13 after re-treatment consisting of water quenching from 800° C. followed by tempering at 575° C. for 4 hours and 2 hours at 650° C, marked ◈.

Under present methods of purchasing material, only the first five determinations can be specified, namely, elastic limit or yield point, tensile strength, elongation, and contraction. Experience indicates that a low figure for the Charpy notched bar transverse test indicates brittleness under suddenly applied stresses. The problem thus resolves itself into one of raising the "Charpy strength" by controlling one or all of the first five qualities. It is evident from the graph that lowering the elastic limit by some 10,000 pounds by proper tempering after quenching has been associated with a great increase in the "Charpy strength."

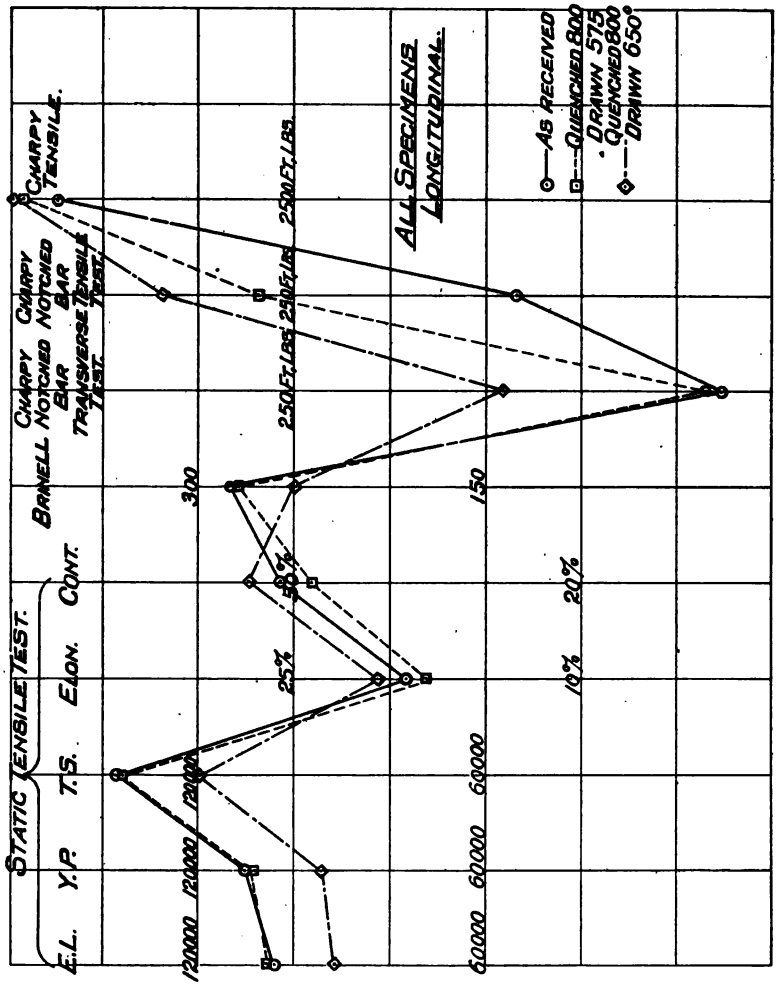
To summarize: the material with a lower elastic limit, lower tensile strength, slightly higher ductility, and lower Brinell hardness has a much higher shock strength as determined by the Charpy notched bar specimen, either tensile or transverse.

These slight variations in the ordinary static tensile properties as determined on longitudinal specimens do not properly account for the great differences present in shock strength as determined by the notched specimens.



Attention is invited to a graph similar to that shown on page 76. The results of a similar series of tests are shown with the exception that all specimens were taken at right angles to the principal axis of the screw, or in other words, were transverse specimens. An inspection of this graph will show that the only consistent relation between any of the Charpy tests and the ordinary static properties lies between ductility and the shock strength. Again referring to the tests taken in a longitudinal direction, a lower elastic limit or yield point seemed

to bring about a higher shock resistance. It seems reasonable to presume that this relation is indirect only. A lower yield point, as determined in a static tensile specimen, if brought about by longer or more complete tempering, will result also in more ductility in the transverse direction. It is the ductility in the transverse direction which seems intimately associated with the shock strength in the longitudinal direction if any change of section is encountered, which is the case in the threaded elevating screw.



Ductility is essential in any given direction for high shock strength. If any abrupt change of section is encountered in a specimen the stresses at right angles to the plane of the applied stress are apparently greatly increased if the rate of application of stress is rapid. Attempts are now being made to determine the critical rate of stress application which brings these apparently obscure factors into play.

INVESTIGATION TO DETERMINE CAUSE OF FAILURE OF BROKEN AXLE ARM FROM 4.7-INCH HOWITZER CARRIAGE, MODEL 1908 MI, NO. 101.

OBJECT.

The object of this investigation was to determine the cause of failure of an axle arm from 4.7-inch howitzer carriage, Model 1908, MI, No. 101.

MATERIAL

Fragments of the broken axle arm from 4.7-inch howitzer, Model 1908, MI, No. 101, were received at this arsenal from Rock Island Arsenal. The failure of this arm occurred while the carriage was being hauled back to the shop after proof-firing. It is stated that the failure occurred while the truck was proceeding at a moderate rate of speed and while crossing a railroad grade crossing.

CONCLUSIONS.

The failure of this axle arm was due to its very low resistance to shock. This is confirmed by the Charpy shock tests made in the laboratory at this arsenal. The mean Charpy value was 17.3 foot-pounds per square inch, which is a result comparable to that obtained upon a good grade of gray iron. Static tensile tests were taken both in the longitudinal and transverse direction of this forging. The elastic limit of the test taken in the transverse direction is approximately 15,000 pounds inferior to that obtained from a specimen taken in the longitudinal direction. The tensile strength obtained from the transverse specimens was approximately 30,000 pounds less than the tensile strength of the longitudinal specimens.

The ductility of the transverse specimens was approximately zero. It has been observed that in a number of other cases where this condition exists, namely, low ductility in the transverse direction, that the Charpy strength is very low. It seems entirely possible that the lack of any definite relation between the Charpy test and the tensile test is due to the fact that the results from tensile specimens taken in the longitudinal direction are generally considered. The question arises as to whether it would not be wise to specify transverse tests for such materials as are subjected to shock, and which involve abrupt section changes. The carbon content of this material was 0.76 per cent.

Experience has also indicated that the material having a carbon content of this amount will invariably have a lower Charpy test than a material of lower carbon content. As it is not at all necessary to use such a high-carbon material for forged steel A, some means should be taken to prevent its use. If material is purchased entirely on physical properties, a limiting chemical composition can

not be prescribed, but the introduction of a shock test or tensile test in the transverse direction would prevent the manufacturer from using such a composition.

EXPERIMENTAL.

The examination consisted of chemical, physical and microscopical tests.

PHYSICAL TESTS.

Four static tensile specimens were taken, three in the transverse direction and marked, respectively, 1, 2, and 3, and one in the longitudinal direction marked 66. The results are tabulated below. The Brinell hardness was taken on the end of the broken tensile specimen.

Marks.	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent).	Contraction (per cent).	Brinell hardness No.
1	45,000	62,500	1.5	1.8	179
2	45,000	69,500	1.5	1.8	187
3	42,000	61,500	1.0	1.8	183
66	60,000	93,333	25.0	65.0	179

The stress-strain diagrams of these four specimens are shown in the following graph. It is to be noted that for the transverse tensile specimens the elastic limit is 45,000 pounds per square inch for specimens Nos. 1 and 2 and 42,000 pounds for specimen No. 3, and for the specimens taken in the longitudinal direction the elastic limit was 60,000 pounds per square inch.

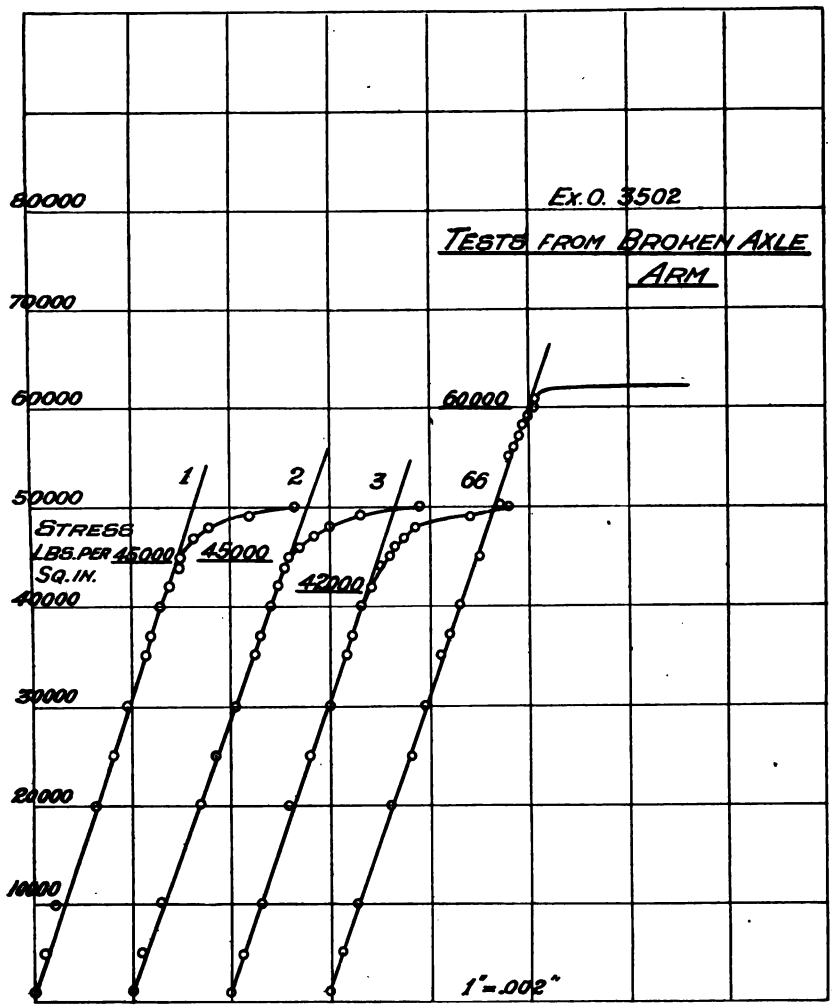
It is to be further noted that great discrepancies exist between the tensile strength of the tensile specimens taken in the transverse direction and the tensile specimens taken in the longitudinal direction. Furthermore, the tensile specimens taken in the transverse direction show practically no ductility, while the longitudinal specimen showed very good elongation and contraction and passed all the requirements of forged steel A.

CHARPY TESTS.

Four notched-bar transverse Charpy tests were taken. These specimens were cut out in the longitudinal direction and gave the following results:

Foot-pounds per square inch.
22.0
16.1
15.1
16.1
Mean.. 17.3

The Charpy qualities of this material, as previously stated in the conclusions of this report, are approximately equal to those which are obtained on a good grade of gray iron. If tensile specimens taken in the longitudinal direction only had been tested, no apparent relation would have existed between the very low Charpy strength and the static properties, namely, elastic limit, tensile strength,



elongation, and contraction. The static properties obtained from the specimens taken in the transverse direction are sufficient in themselves to warrant the rejection of the piece. It would not be fair to the manufacturer, however, to insist upon the same physical qualities from specimens taken in the transverse direction as are now being required for specimens taken in the longitudinal direction.

CHEMICAL ANALYSIS.

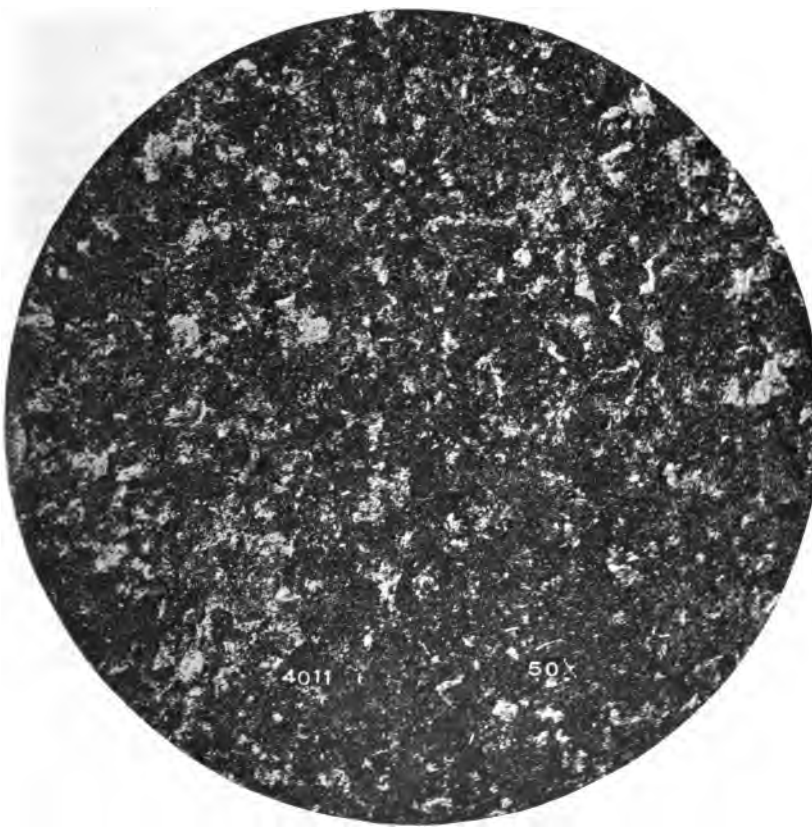
Chemical analysis from the sample taken from the broken axle arm gave the following results:

C.	Mn.	Si.	S.	P.	Ni.	Cr.	Va.
Per cent. 0.76	*Per cent.* 0.45	*Per cent.* 0.136	*Per cent.* 0.034	*Per cent.* 0.007	.....	.....	.....

This composition, upon proper treatment, would be expected to give satisfactory physical properties when determined in the customary manner. It is extremely doubtful, however, if material of this carbon content will give as satisfactory results on tensile specimens taken in the transverse direction as will material of a lower carbon. All the evidence so far obtained upon the Charpy machine indicates that the carbon content has a decided influence on the resistance to shock, a high carbon being associated with low-shock resistance. For this reason a material of this carbon content should be avoided whenever possible.

MICROEXAMINATION.

Two photomicrographs at 50 and 500 diameters, respectively, are shown facing this page. The structure is almost entirely sorbitic, and it is possible that tempering at a higher temperature would improve both the ductility in the specimens taken in the transverse direction and the resistance to shock.



74-1

74-2

NEW COMPOSITION OF SHRAPNEL BALLS.

OBJECT.

The object of this investigation was to determine whether the bariumcalciumlead alloy was a suitable substitute for the antimony-lead composition now being used. Information was requested as to the degree of hardness and lack of brittleness in balls made from new composition with similar tests on lead-antimony balls for purposes of comparison.

MATERIAL.

The material used was 50 six-sided shrapnel balls containing 12.5 per cent antimony and 50 spherical balls of the experimental shrapnel metal manufactured by United Lead Co.

METHOD OF INVESTIGATION.

Chemical and microscopical analyses were made on the new composition shrapnel ball. The relative hardness of the two materials was determined by both the scleroscope and the impact test.

CONCLUSIONS.

The average scleroscope reading on the new composition shrapnel ball was 9.5. The average reading on the six-sided antimony-lead ball was 5.6, the hardness of the new composition being about 70 per cent greater. The results of the impact test showed that the antimony-lead ball was flattened more for a given weight and drop than the new composition ball. The calcium-lead ball spalled off very badly under the impact test and gave indications of the existence of a brittle surface coating.

As the two metals, barium and calcium, are both readily oxidizable, it is thought that the oxidization of these two elements may lead to the brittleness in the surface coating. As there is a possibility that this brittleness would extend throughout the ball after a lapse of sufficient time, it would not seem advisable to use this alloy for shrapnel balls without first carrying out experiments to determine this fact.

EXPERIMENTAL.

Scleroscope test.—Several of the balls of both kinds were filed down until a surface was obtained on which the scleroscope hardness could be taken. The minimum reading on the bariumcalcium-lead ball was 9, the maximum reading 10, the mean value of a number of readings being 9.5.

The minimum value of the readings on the antimony lead ball was 5 and the maximum 6, the mean value of a number of readings being 5.6.

The hardness of the barium-calcium-lead ball was 70 per cent greater than the hardness of the antimony-lead ball.

CHEMICAL ANALYSIS.

The results of the chemical analysis of the new composition alloy were as follows:

	Per cent.
Barium	0.23
Calcium	.28
Iron	Trace.
Copper	None.
Lead, by difference	99.49

IMPACT TESTS.

For the impact test five balls of each kind were selected for each weight and drop. The instrument employed consisted of a 500-pound anvil. The falling weight was 10 pounds. The weight was released at various heights from the face of the anvil by the burning of a cord supporting the weight. The heights of fall selected were 12, 18, 24, 36, 48, 60, 90, 150, and 210 inches.

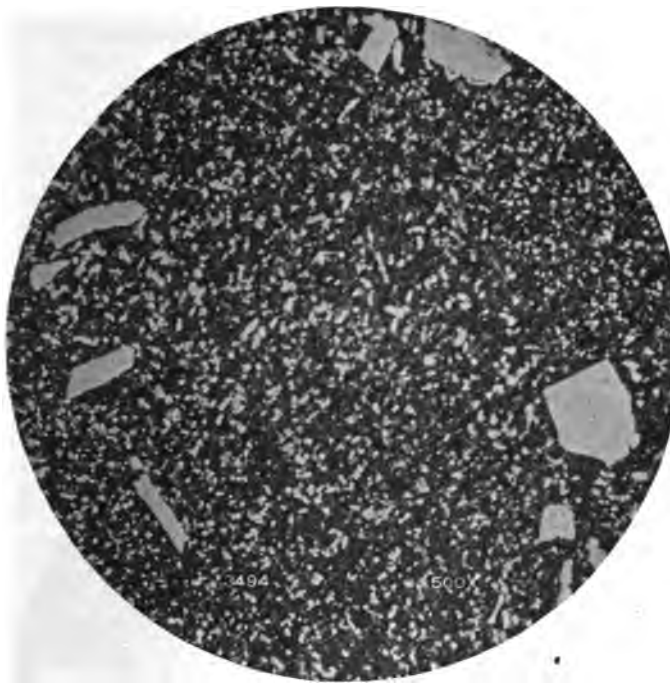
The data tables inserted show the diameter of the ball before impact, the diameter after impact, height of fall, reduction of diameter, and per cent reduction of diameter. The results obtained by this series of experiments are plotted in the form of a graph on page 82. The ordinates represent the reduction of diameter of the ball by impact; the abscissæ the height of drop. The values obtained are very consistent and show that the reduction of diameter of the new compositon was less than that of the lead-antimony ball. From the form of the curve it is to be noted that as the height becomes great and the per cent of reduction of diameter increases the two curves approach very closely.

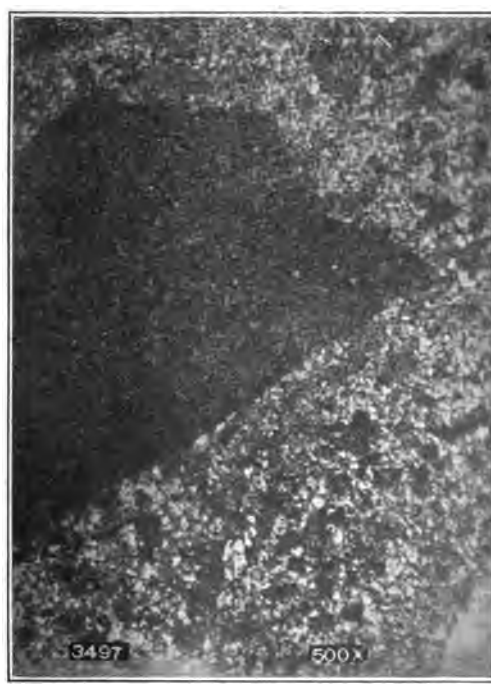
Facing page 82, the photographs of the ball after impact are shown. Discussing these in order, it is to be noted that in photograph No. 3485, height of drop 12 inches, the new lead alloy begins to show the tendency of the surface layer to crack and spall. The antimony-lead balls were but slightly cracked in one or two instances by this same impact.

Photograph No. 3486, height of drop 18 inches, the spalling of the surface layer became very marked in the new lead alloy. It is to be noted at this point that after the surface layer had been broken off the alloy underneath was very bright with a good luster, but after standing for a few minutes it very rapidly darkened until it became almost black in color, resembling the outside of balls as received.

Photograph No. 3487, height of drop 24 inches, the antimony-lead composition ball showed the first serious cracking under this impact. The new lead alloy balls behaved the same as under the 18-inch impact, excepting that the spalling was slightly more marked.

Photograph No. 3488, height of drop, 36 inches. It is to be noticed in this photograph that the new lead alloy scaled off very badly. Pieces of this scale attached to the balls is to be noted in the photograph. Under the new lead alloy balls in this photo-





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77–2

graph is shown another new lead alloy ball which was subjected to the same impact. The ball just referred to was immersed in nitric acid until the dark surface layer had been completely dissolved. It was immediately subjected to the impact test after removing from the acid and very little scaling occurred. This would point to the conclusion that the surface layer was superficial only in its extent. This is not consistent with the fact observed that the scale which was broken from these balls varied in thickness from one thirty-second to one sixty-fourth of an inch.

Photograph No. 3489, height of drop, 48 inches. The new lead alloy balls did not seem to scale as badly as under the lower drop of 36 inches. When the height of drop was raised to 60 inches, photograph No. 3490, the scaling was, however, very marked. As the height of drop was made greater than 60 inches, photographs Nos. 3491, 3492, and 3493, respectively, the differences in behavior in the two compositions was not so well defined.

The nature of barium and calcium would at once suggest that they would readily oxidize, but it is thought that this action would be especially marked in moist air. If it is the oxidizing action which makes the surface of the new composition ball brittle, it does not seem safe to assume that this action would be confined to the surface layers. The surface layer might form a protective coating which would prevent further oxidation, but it would seem very probable that such would not be the case. It would seem advisable that a series of experiments should be carried out on this alloy after it had been subjected to seriously oxidizing influences by hastening the oxidizing reaction by slight increase in temperature, maintaining in an oxygen atmosphere, etc. It is thought that data could thus be obtained in the course of a few months regarding the nature of the gradual oxidation of the alloy IF such a condition existed.

MICROSCOPICAL.

Microscopical examination of the lead-antimony ball showed that the composition was such that a slight excess of antimony existed over that necessary for the eutectic, namely, 12.5 per cent antimony, 87.5 per cent lead.[1] Micrograph No. 3494, facing page 77, at 500 diameters shows the eutectic with crystals of excess antimony.

Micrograph No. 3495, facing page 77, showing the structure of the barium calcium-lead alloy, has one point of interest. The broad, dark boundary lines of the grain would suggest an inner granular substance of some sort.

Micrograph No. 3497, facing page 77, shows the structure of the alloy near the surface. The exceedingly large grain as compared to the grain size in the interior of the ball is very striking. This occurrence of the large grain near the surface of the ball may assist in accounting for the brittleness observed at this point. In one or two cases, however, small grains occurred at the surface of the ball so that no definite conclusions could be drawn concerning the coincidence of this large grain with the brittleness observed. It is thought, however, that the artificial aging of the shrapnel ball will materially assist in the understanding of this phenomenon and its relation to grain growth.

[1] Contermann. Teits, Anorg. Chem., 1907, Vol. IV, p. 419.

In claims made by the manufacturers it is stated that—

It may well be taken for granted that the quality of brittleness is not present in the barium-calcium-lead ball, since this metal is composed so largely of lead, which does not possess brittleness. Antimony, on the other hand, being such an important part of the antimonial-lead ball, is an exceedingly brittle metal and must lend this quality to the ball.

The scientific justification of this statement is not clear.

The introduction of 1 per cent of an element in any alloy may produce serious brittleness. Furthermore, the introduction of 12.5 per cent of a brittle metal does not necessarily imply that the resulting alloy will be brittle.

DENSITY DETERMINATIONS.

Density determinations were made on both the old and the new compositions by the method of determining the loss of weight in water.

Specimen.	Barium-calcium-lead ball.	Antimony-lead ball.
1	11.19	10.51
2	11.22	10.52
3	11.20	10.51
Mean	11.20	10.51

It would seem, as previously pointed out in the conclusions of this report, that the barium-calcium-lead shrapnel ball might become brittle after aging. Should this occur in a loaded shrapnel case the results would certainly not be satisfactory. As this is apparently the only difficulty in the use of this material for shrapnel balls which now suggests itself to the laboratory, it is thought that experiments previously referred to should be first carried out before the adoption of this material as a substitute for the antimony-lead ball.

HEIGHT OF DROP, 48 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.495	0.211	0.284	57.4
2	.495	.208	.287	58.0
3	.497	.210	.287	57.8
4	.498	.209	.289	57.9
5	.503	.213	.290	57.7

ROUND BALLS.

1	0.501	0.246	0.255	50.9
2	.492	.250	.242	49.3
3	.504	.250	.254	50.5
4	.498	.250	.248	49.8
5	.500	.251	.249	49.8

Falling weight = 10 pounds.

HEIGHT OF DROP, 36 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.505	0.255	0.250	49.5
2	.500	.250	.250	50.0
3	.496	.249	.257	51.8
4	.499	.247	.252	50.5
5	.495	.248	.247	50.0

ROUND BALLS.

1	0.495	0.285	0.210	42.5
2	.500	.290	.210	42.0
3	.495	.292	.203	41.0
4	.496	.276	.220	44.4
5	.497	.297	.200	40.3

Falling weight = 10 pounds.

HEIGHT OF DROP, 24 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.494	0.297	0.197	39.8
2	.500	.298	.202	40.4
3	.502	.300	.202	40.3
4	.500	.300	.200	40.0
5	.500	.296	.204	40.4

BLACK ROUND BALLS.

1	0.500	0.345	0.155	31.0
2	.495	.337	.158	32.0
3	.497	.340	.157	31.6
4	.496	.337	.159	32.0
5	.500	.300	[1]	.....

[1] Error in test.

Falling weight = 10 pounds.

HEIGHT OF DROP, 18 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.500	0.327	0.173	34.6
2	.498	.327	.171	34.3
3	.495	.327	.168	34.0
4	.495	.323	.172	34.8
5	.500	.330	.170	34.0

ROUND BALLS.

1	0.497	0.371	0.126	25.4
2	.492	.364	.128	26.0
3	.496	.366	.130	26.2
4	.496	.361	.135	27.2
5	.495	.371	.124	25.0

Falling weight = 10 pounds.

HEIGHT OF DROP, 12 INCHES.

ANTIMONY-LEAD BALL.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.498	0.364	0.134	26.8
2	.499	.365	.134	26.8
3	.498	.365	.133	26.6
4	.498	.369	.129	25.8
5	.500	.363	.137	27.4

BARIUM-CALCIUM-LEAD BALL.

1	0.495	0.397	0.098	19.8
2	.490	.384	.106	21.6
3	.492	.395	.097	19.7
4	.505	.405	.100	19.8
5	.500	.400	.100	20.0

Falling weight = 10 pounds.

HEIGHT OF DROP, 60 INCHES

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.507	0.183	0.324	64.1
2	.504	.182	.322	63.8
3	.494	.182	.312	63.2
4	.495	.178	.317	64.1
5	.505	.182	.323	64.0

ROUND BALLS.

1	0.500	0.220	0.280	56.1
2	.510	.213	.297	58.2
3	.496	.220	.276	55.6
4	.502	.216	.286	57.2
5	.499	.221	.278	55.6

Falling weight = 10 pounds.

HEIGHT OF DROP, 90 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.500	0.135	0.365	73.0
2	.498	.132	.366	73.4
3	.502	.133	.369	73.5
4	.497	.132	.365	73.4
5	.499	.132	.367	73.5

ROUND BALLS.

1	0.502	0.164	0.338	67.4
2	.503	.149	.354	70.4
3	.508	.157	.351	69.0
4	.496	.167	.329	66.4
5	.501	.157	.344	68.7

Falling weight = 10 pounds.

HEIGHT OF DROP, 150 INCHES.

SIX-SIDED BALLS.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.499	0.084	0.415	83.1
2	.498	.083	.415	83.2
3	.499	.083	.416	83.2
4	.498	.084	.414	83.0
5	.500	.080	.420	83.9

ROUND BALLS.

1	0.500	0.096	0.404	80.8
2	.494	.099	.405	82.0
3	.496	.103	.393	79.3
4	.495	.098	.397	80.2
5	.495	.098	.397	80.2

Falling weight = 10 pounds.

HEIGHT OF DROP, 210 INCHES.

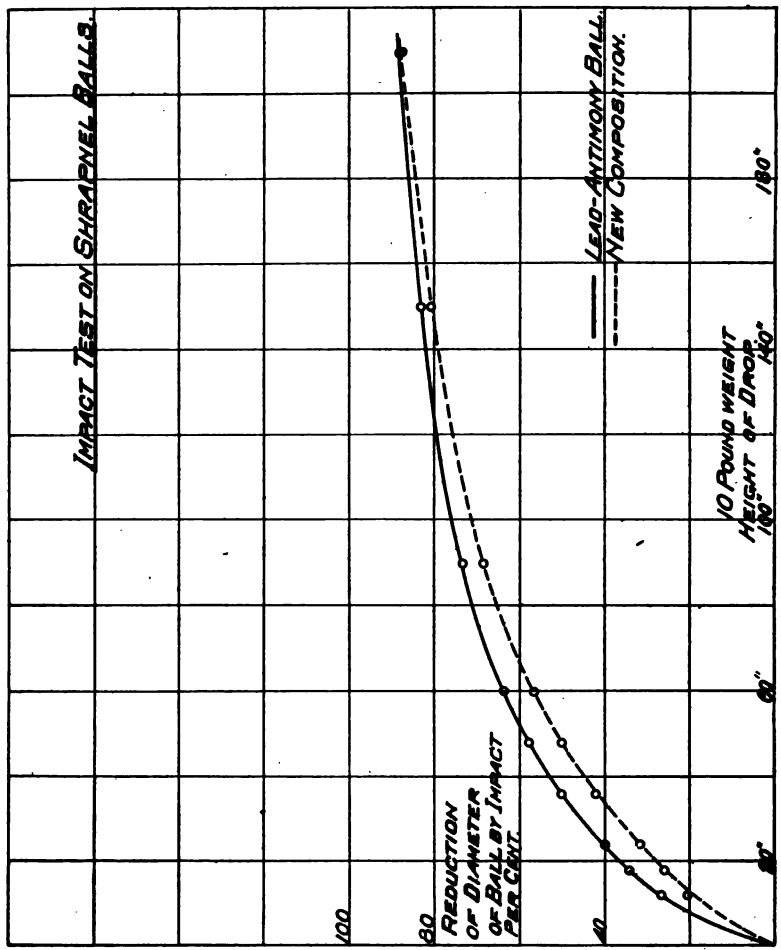
SIX-SIDED BALL.

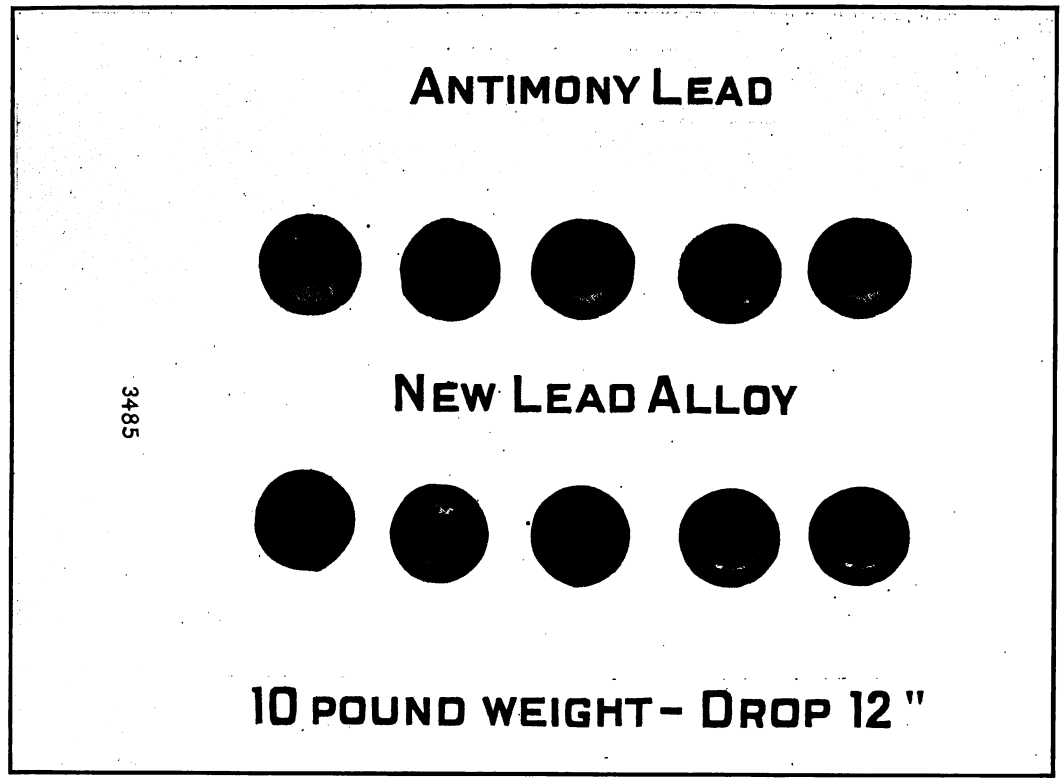
Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.495	0.055	0.440	88.8.
2	.497	.056	.441	88.6
3	.500	.056	.444	88.0

ROUND BALLS.

1	0.505	0.062	0.443	87.5
2	.496	.540		
3	.499	.610	.438	87.7

Falling weight = 10 pounds.


Impact Test on Shrapnel Balls.
Lead-Antimony Ball.
New Composition.
10 Pound Weight
Height of Drop
100"
120"
60"
80"
40"
Reduction of Diameter of Ball by Impact Per Cent.
100
80
40



3485

82-2

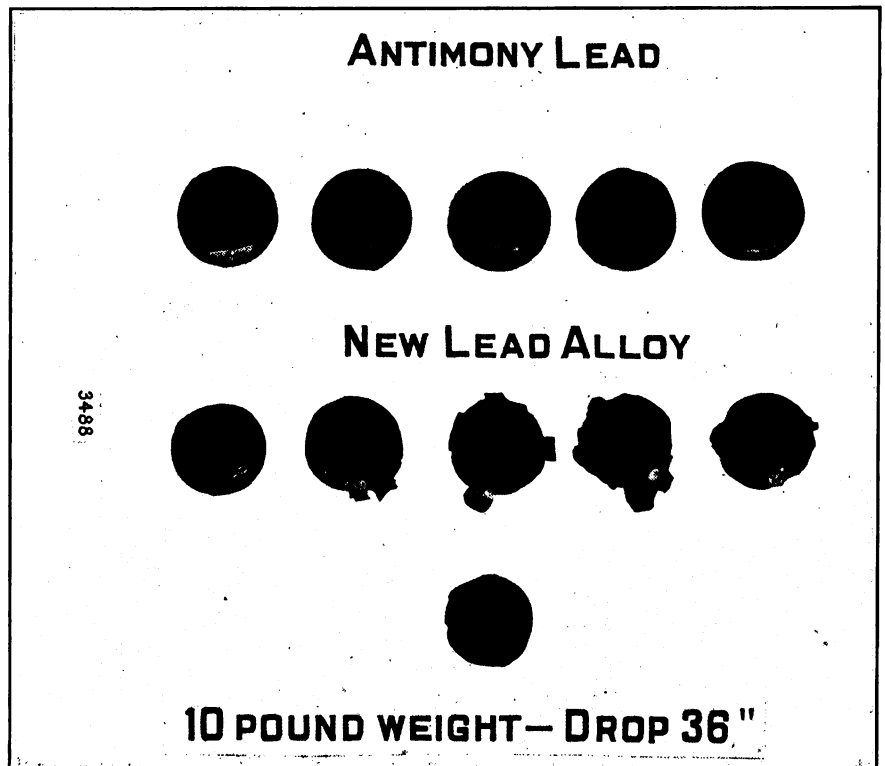
ANTIMONY LEAD

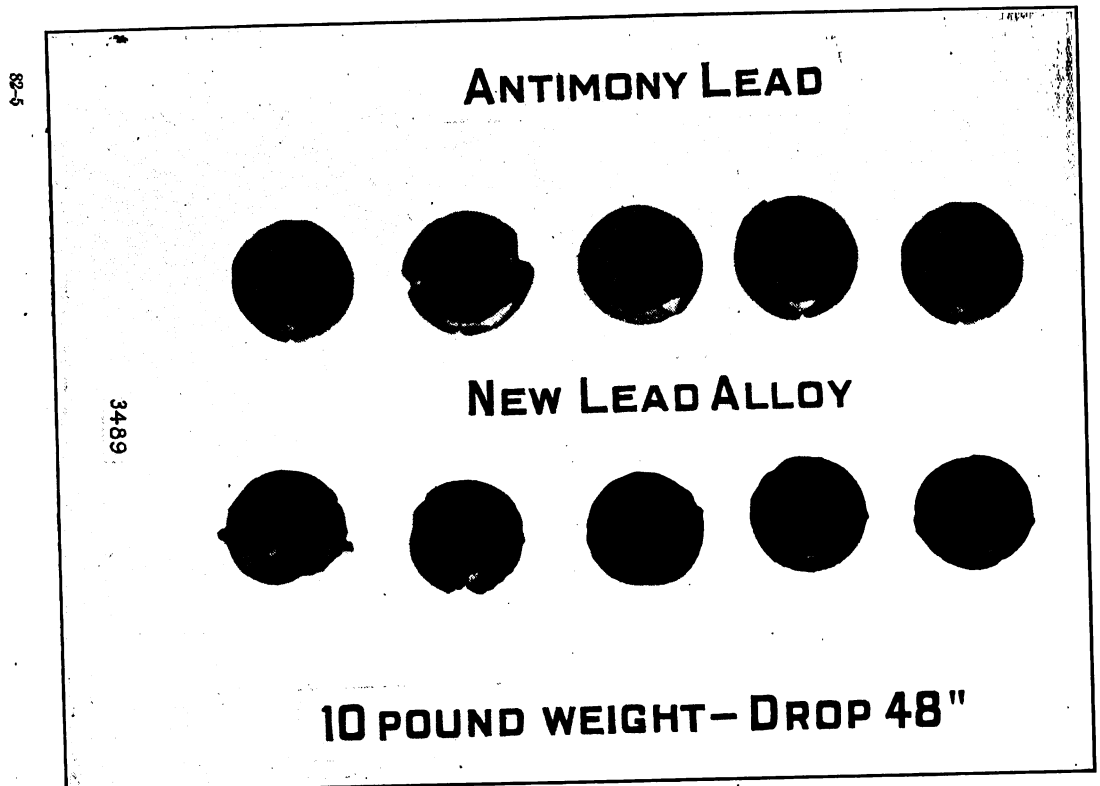
NEW LEAD ALLOY

3486

10 POUND WEIGHT – DROP 18"

82-3


ANTIMONY LEAD
NEW LEAD ALLOY
34-88
10 POUND WEIGHT— DROP 36"


ANTIMONY LEAD
NEW LEAD ALLOY
10 POUND WEIGHT—DROP 48"
3489

ANTIMONY LEAD

NEW LEAD ALLOY

3490

10 POUND WEIGHT— DROP 60"

82-7
31082—18——8

ANTIMONY LEAD
NEW LEAD ALLOY
3492
10 POUND WEIGHT – DROP 150"

82-9

ANTIMONY LEAD

NEW LEAD ALLOY

3493

10 POUND WEIGHT— DROP 210"

EFFECT OF AGING ON BARIUM-CALCIUM-LEAD ALLOY SHRAPNEL BALLS.

OBJECT.

The object of this investigation was to determine if the superficial brittleness noted in the tests on barium-calcium-lead alloy shrapnel balls would in time, under service conditions of storage, extend throughout the body of the ball.

CONCLUSIONS.

There was practically no difference observed between the behavior of the balls tested and reported, and those exposed to laboratory conditions for 8 months.

The balls which had been exposed to the weather for 134 days showed little, if any, difference in spalling. The group subjected to impact when the weight fell 36 inches was spalled more severely than the balls which had been exposed to laboratory conditions when tested under the same conditions.

Comparing the groups subjected to the hot and cold water treatment, it was noted that those exposed to hot water spalled more seriously than those subjected to the cold-water treatment. Both groups gave more spalling than any of those exposed to atmospheric conditions.

The balls which were kept in the drying oven at 110° C., for 23 days, showed less spalling than any of the other lots tested. Deep surface cracks were apparent after impact, but the surface skin did not fly off. These balls gave a greater reduction of diameter under impact than the previous groups tested.

The balls subjected to the potassium chlorate and potassium permanganate solutions showed serious brittleness which penetrated very deeply into the body of the ball.

It seems evident that the brittle surface layer present in the calcium-barium-lead composition is intimately associated with the oxidation of the calcium and barium. The results obtained in these experiments confirm this view as the oxidizing solutions gave a very serious brittleness.

The rate of penetration of this oxidation, with its consequent brittleness, as indicated by the experiments, is probably very slow under atmospheric conditions. Very dilute oxidizing solutions gave a rapid penetration of brittleness.

In view of the above facts it would seem essential that some decided reason exist for the change from the lead-antimony composition to the calcium-barium-lead alloy before this change is made. It is very probable that the new composition ball would not become seriously brittle with age under normal storage conditions, but in view of the fact that this alloy is apparently not in a completely stable condition, its adoption would not seem advisable unless economic or other sufficient reasons so warranted.

MATERIAL.

The material studied consisted of approximately 300 barium-calcium-lead alloy shrapnel balls forwarded from Frankford Arsenal.

METHOD OF INVESTIGATION.

Seven lots of the balls were exposed to various oxidizing and artificial aging conditions as noted below:

(1) Exposed to laboratory conditions for 8 months.

(2) Exposed to weather on roof of testing laboratory 134 days.

(3) After exposure to laboratory conditions for 7 months, placed in water at 20° C. for 23 days.

(4) After exposure to laboratory conditions for 7 months, placed in water at 60° C. for 23 days.

(5) After exposure to laboratory conditions for 7 months, placed in drying oven at 110° C. for 23 days.

(6) After exposure to laboratory conditions for 7 months, placed in 0.2 per cent solution of potassium chlorate for 23 days.

(7) After exposure to laboratory conditions for 7 months, placed in 0.2 per cent solution of potassium permanganate for 23 days.

After the above treatments, the various balls were tested under impact, using a 10-pound weight with a variable height of drop.

EXPERIMENTAL.

After the balls had been exposed to the various conditions outlined under "Method of investigation" they were wiped free from any adhering particles and carefully measured before testing. After impact their thickness was determined and the per cent reduction of diameter computed from the data thus obtained. A 10-pound weight was used throughout the experiments, and the height of drop varied.

The following table summarizes the results obtained. It is to be noted from this table that the greater reduction of diameter under any particular height of drop is associated with more spalling of the outside layers. A comparison of the balls subjected to dilute potassium chlorate solution with those exposed to laboratory conditions will illustrate this point when considered in connection with the photograph of the balls of the series under discussion. The only exception to this general rule were the balls treated at 110° C.

The complete data tables together with the photographs of the balls after test are included in this report. No detailed discussion of these results seems necessary, as an inspection of the various photographs

EXPOSED TO LABORATORY CONDITIONS 8 MONTHS.

DROP 12"

DROP 18"

3758

which are all properly labeled, will show the behavior of the brittle layer after the different treatments.

Reduction of diameter after impact.

	Height of drop (inches).								
	12	18	24	36	48	60	90	150	210
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Balls tested August, 1916	20.2	25.9	31.6	42.0	50.1	56.5	68.4	80.5	87.6
Balls stored in laboratory 8 months	19.5	26.2	32.6	42.0	52.5	60.3	73.1	81.7	87.6
Balls exposed to weather 134 days	19.2	26.3	34.2	41.8	51.7	57.5	69.9	82.4	87.9
Balls in cold water at 20° C. 23 days	20.2	.....	33.2	45.3	.....	67.4	73.4	83.7	.....
Balls in warm water at 60° C. 23 days	20.4	.....	25.4	47.1	.....	66.2	77.0	83.2	.....
Balls in drying oven at 110° 23 days	31.7	.....	45.3	56.2	.....	69.5	79.0	85.0	.....
Balls in dilute potassium chlorate solution for 23 days	34.6	.....	42.5	51.0	.....	71.8	79.0	86.3	.....
Balls in dilute potassium permanganate solution for 23 days	35.9	.....	47.7	64.0	.....	72.0	84.9	88.1	.....

Balls exposed to laboratory conditions for 8 months.

HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.500	0.396	0.104	20.8
2	0.494	0.405	0.089	18.0
3	0.497	0.398	0.099	19.9
4	0.496	0.395	0.101	20.4
5	0.493	0.401	0.092	18.7

HEIGHT OF DROP, 18 INCHES.

1	0.493	0.368	0.125	25.3
2	0.498	0.373	0.125	25.1
3	0.493	0.363	0.130	26.3
4	0.498	0.363	0.135	27.1
5	0.504	0.365	0.139	27.5

Falling weight = 10 pounds.

Balls exposed to laboratory conditions for 8 months—Continued.

HEIGHT OF DROP, 24 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.492	0.313	0.179	36.4
2	0.500	0.339	0.161	32.3
3	0.487	0.334	0.153	31.4
4	0.498	0.346	0.152	30.5
5	0.496	0.333	0.163	32.7

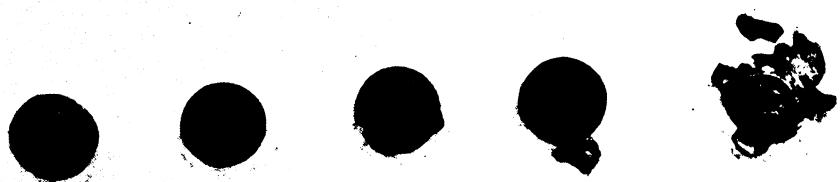
HEIGHT OF DROP, 36 INCHES.

1	0.493	0.297	0.196	39.7
2	0.499	0.287	0.212	41.6
3	0.500	0.270	0.230	46.0
4	0.497	0.278	0.219	44.0
5	0.487	0.299	0.188	38.7

Falling weight = 10 pounds.

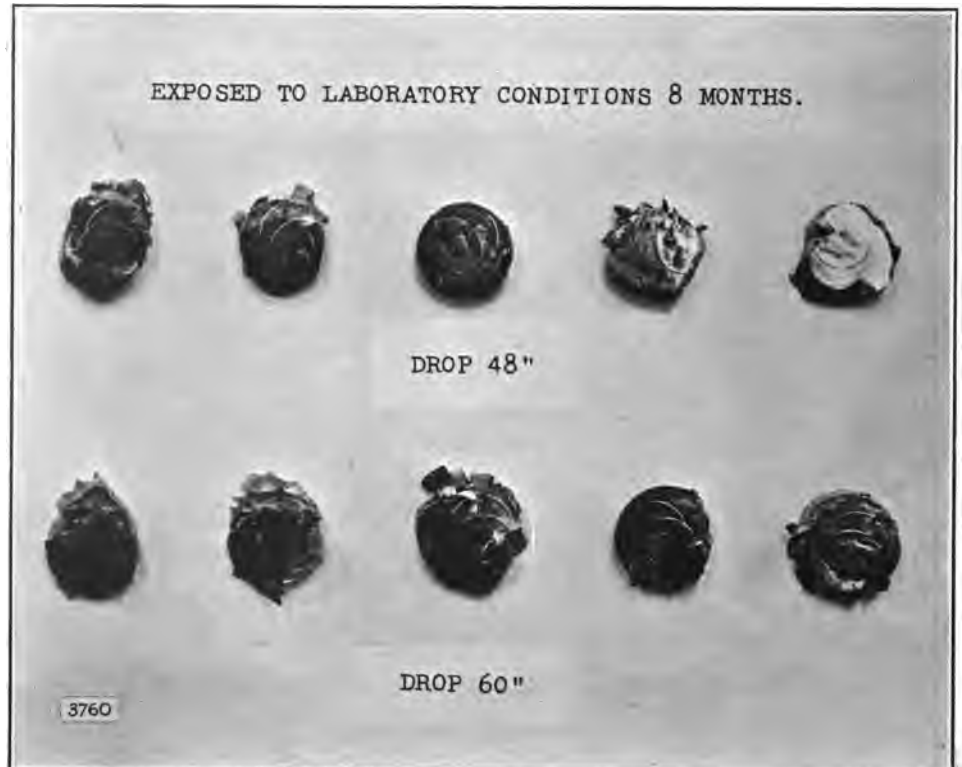
EXPOSED TO LABORATORY CONDITIONS 8 MONTHS.

DROP 24"



DROP 36"

3759


EXPOSED TO LABORATORY CONDITIONS 8 MONTHS.
DROP 48"
DROP 60"
3760

Balls exposed to laboratory conditions for 8 months—Continued.

HEIGHT OF DROP, 48 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.490	0.223	0.267	54.4
2	0.494	0.224	0.270	54.6
3	0.500	0.250	0.250	50.0
4	0.488	0.234	0.254	52.0
5	0.497	0.239	0.258	51.9

HEIGHT OF DROP, 60 INCHES.

1	0.493	0.189	0.304	61.7
2	0.493	0.178	0.315	63.9
3	0.496	0.194	0.302	60.8
4	0.485	0.210	0.275	56.7
5	0.494	0.205	0.289	58.5

Falling weight = 10 pounds.

Balls exposed to laboratory conditions for 8 months—Continued.

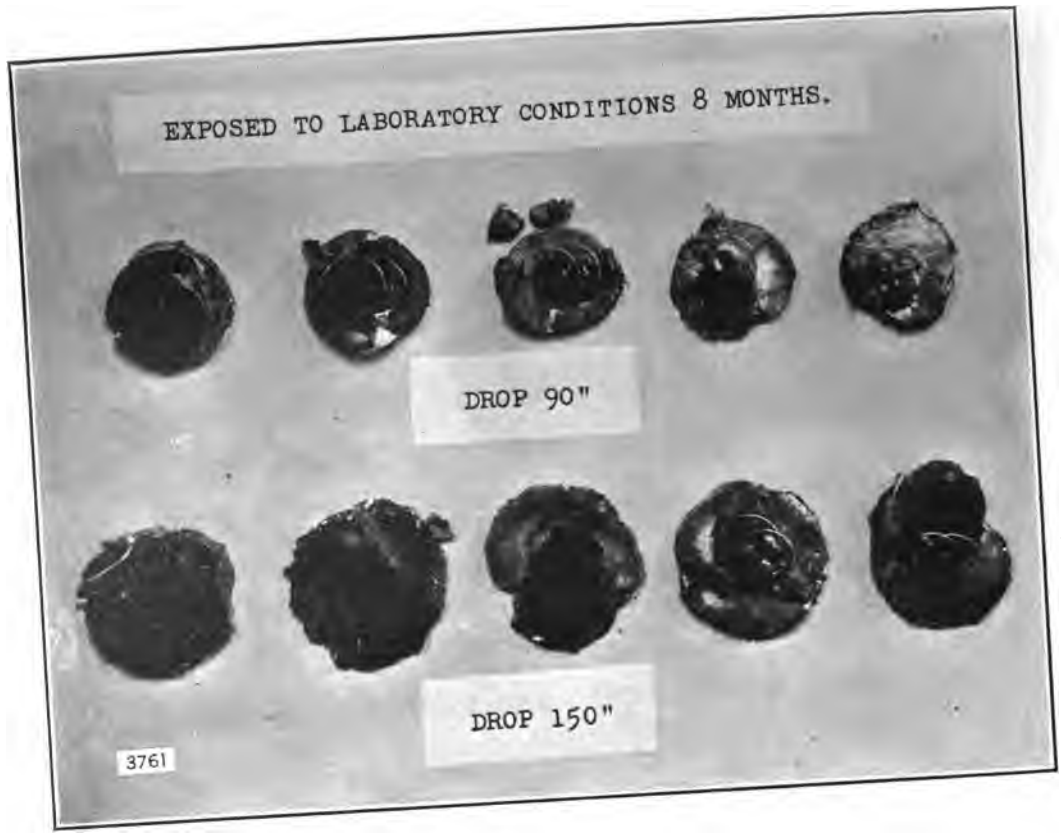
HEIGHT OF DROP, 90 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.497	0.162	0.335	67.4
2	0.488	0.157	0.331	67.8
3	0.497	0.113	0.384	76.1
4	0.497	0.099	0.398	80.2
5	0.500	0.130	0.370	74.0

HEIGHT OF DROP, 150 INCHES.

1	0.497	0.103	0.394	79.2
2	0.489	0.075	0.414	84.5
3	0.496	0.085	0.411	83.0
4	0.498	0.092	0.406	81.6
5	0.491	0.098	0.393	80.2

Falling weight = 10 pounds.


EXPOSED TO LABORATORY CONDITIONS 8 MONTHS.
DROP 90"
DROP 150"
3761

EXPOSED TO LABORATORY CONDITIONS 8 MONTHS.

DROP 210"

3762

Balls exposed to laboratory conditions for 8 months—Continued.

HEIGHT OF DROP, 210 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.493	0.057	0.436	88.4
2	0.495	0.062	0.433	88.0
3	0.493	0.067	0.426	86.4
4	0.499	0.075	0.424	85.8
5	0.494	0.052	0.442	89.4

Falling weight = 10 pounds.

31082—18——9

Balls exposed to weather on roof of testing laboratory for 134 days.

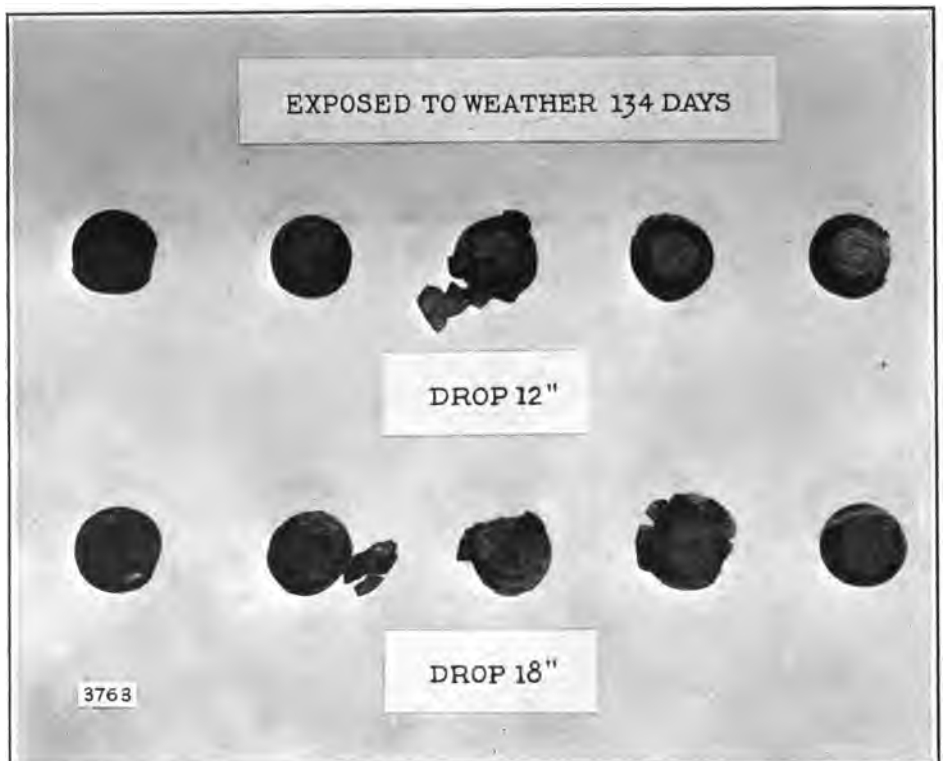
HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.488	0.385	0.103	21.1
2	0.498	0.410	0.088	17.7
3	0.498	0.402	0.096	19.3
4	0.501	0.408	0.093	18.6
5	0.496	0.399	0.097	19.6

HEIGHT OF DROP, 18 INCHES.

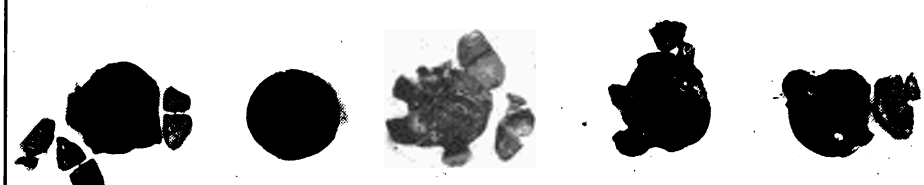
1	0.495	0.360	0.135	27.0
2	0.494	0.365	0.129	26.1
3	0.493	0 358	0.135	27.4
4	0.491	0.353	0.138	28.1
5	0.495	0.370	0.125	25.2

Falling weight = 10 pounds.


EXPOSED TO WEATHER 134 DAYS
DROP 12"
DROP 18"
3763

EXPOSED TO WEATHER 134 DAYS

DROP 24"



3764

DROP 36"

Balls exposed to weather on roof of testing laboratory for 134 days—Continued.

HEIGHT OF DROP, 24 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.500	0.316	0.184	36.8
2	.494	.338	.156	31.5
3	.488	.305	.183	37.5
4	.500	.332	.168	33.6
5	.494	.338	.156	31.6

HEIGHT OF DROP, 36 INCHES.

1	0.485	0.282	0.203	41.8
2	.488	.287	.201	41.2
3	.503	.291	.212	42.1
4	.491	.287	.204	41.6
5	.498	.287	.211	42.6

Falling weight = 10 pounds.

Balls exposed to weather on roof of testing laboratory for 134 days—Continued.

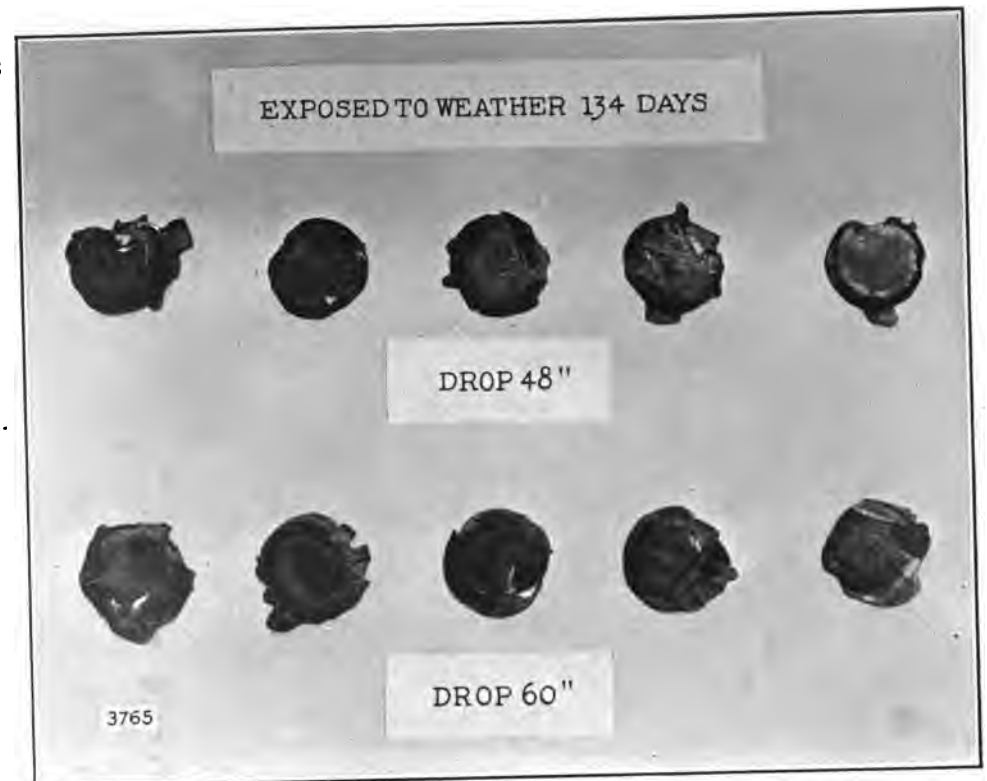
HEIGHT OF DROP, 48 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameterb y impact(per cent).
1	0.501	0.236	0.265	55.0
2	.489	.237	.252	51.6
3	.495	.245	.250	50.5
4	.491	.233	.258	52.5
5	.496	.253	.243	49.0

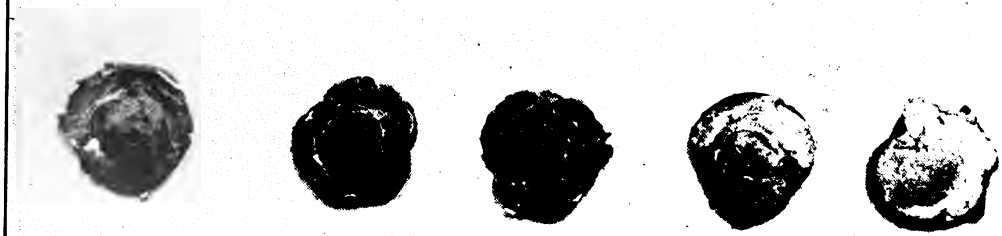
HEIGHT OF DROP, 60 INCHES.

1	0.494	0.208	0.286	57.5
2	.495	.201	.294	59.4
3	.498	.215	.283	56.8
4	.498	.216	.282	56.6
5	.500	.213	.287	57.4

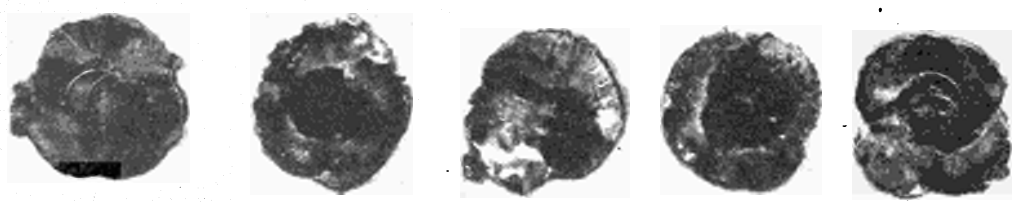
Falling weight = 10 pounds.


EXPOSED TO WEATHER 134 DAYS
DROP 48"
DROP 60"
3765

EXPOSED TO WEATHER 134 DAYS



DROP 90"



DROP 150"

3766

EXPOSED TO WEATHER 134 DAYS.
DROP 210"
3767

Balls exposed to weather on roof of testing laboratory for 134 days—Continued.

HEIGHT OF DROP, 90 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.502	0.150	0.352	70.0
2	.491	.147	.344	70.0
3	.495	.142	.353	71.2
4	.493	.160	.333	67.5
5	.495	.142	.353	71.2

HEIGHT OF DROP, 150 INCHES.

1	0.497	0.072	0.425	85.5
2	.498	.095	.403	80.9
3	.493	.073	.420	85.2
4	.496	.097	.399	80.3
5	.500	.098	.402	80.3

HEIGHT OF DROP, 210 INCHES.

1	0.500	0.064	0.436	87.2
2	.475	.046	.429	90.2
3	.490	.066	.424	86.5
4	.488	.062	.426	87.3
5	.495	.057	.438	88.5

Falling weight = 10 pounds.

Balls exposed to laboratory conditions for 7 months, then placed in water at 20° C. for 23 days.

HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.501	0.408	0.093	18.6
2	.490	.392	.098	20.0
3	.497	.383	.114	22.9
4	.503	.406	.097	19.2

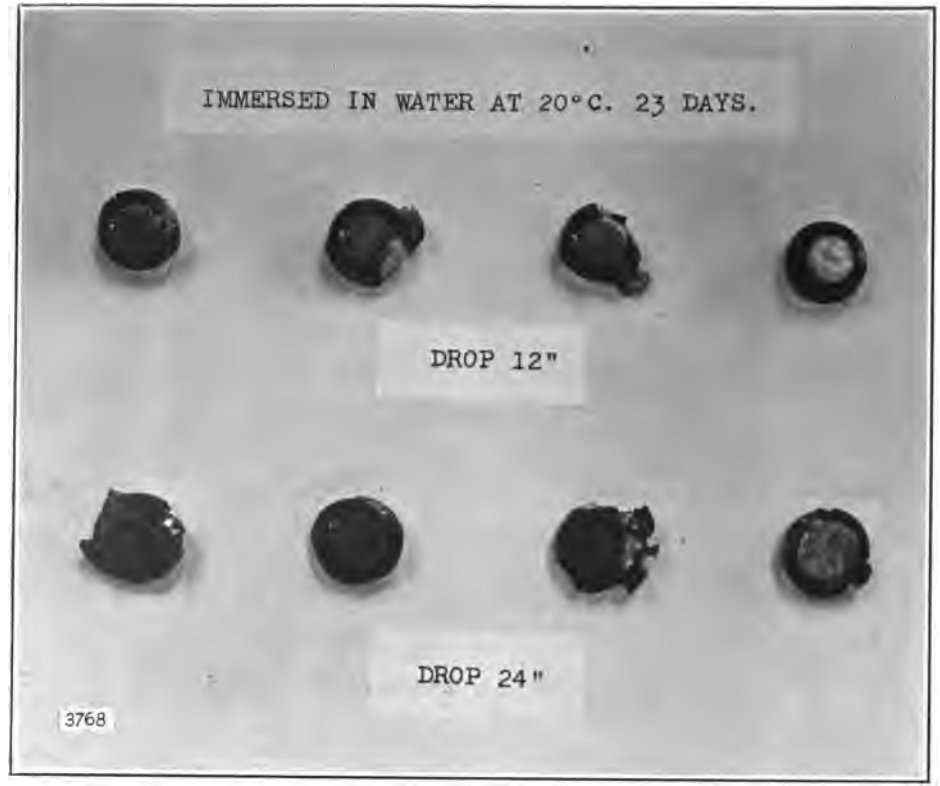
HEIGHT OF DROP, 24 INCHES.

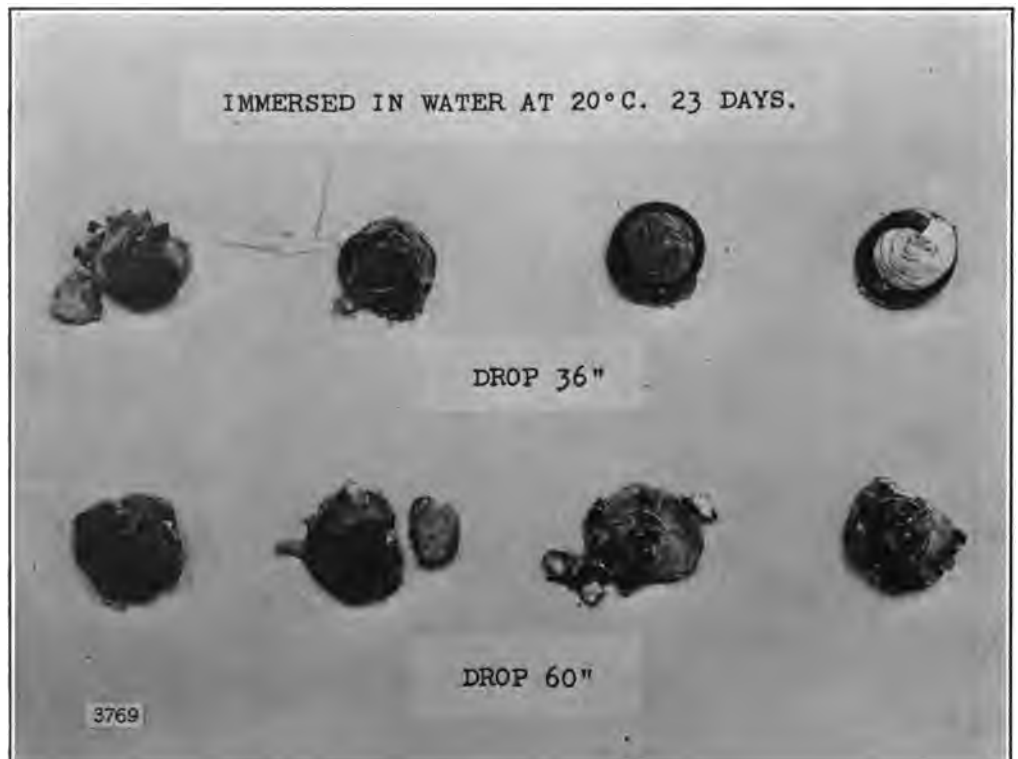
1	0.501	0.337	0.164	32.7
2	.501	.337	.164	32.7
3	.498	.327	.171	34.3
4	.498	.333	.165	33.2

HEIGHT OF DROP, 36 INCHES.

1	0.497	0.243	0.254	51.0
2	.495	.256	.239	48.3
3	.494	.291	.203	41.1
4	.480	.283	.197	41.0

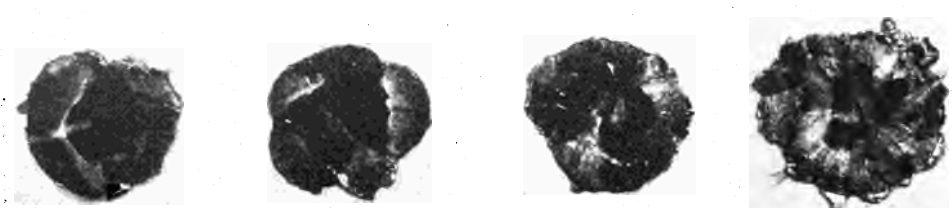
Falling weight = 10 pounds.


IMMERSED IN WATER AT 20°C. 23 DAYS.
DROP 12"
DROP 24"
3768


IMMERSED IN WATER AT 20°C. 23 DAYS.
DROP 36"
DROP 60"
3769

IMMERSED IN WATER AT 20°C. 23 DAYS.

DROP 90"



DROP 150"

3770

Balls exposed to laboratory conditions for 7 months, then placed in water at 20° C. for 23 days—Continued.

HEIGHT OF DROP, 60 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.493	0.201	0.292	59.2
2	.490	.152	.338	69.0
3	[1].500	.111	.389	77.8
4	.503	.183	.320	63.6

HEIGHT OF DROP, 90 INCHES.

1	0.496	0.123	0.373	75.2
2	.497	.152	.345	69.3
3	.498	.108	.390	78.3
4	.500	.146	.354	70.8

HEIGHT OF DROP, 150 INCHES.

1	0.489	0.089	0.400	81.7
2	.500	.095	.405	81.0
3	.490	.076	.414	84.4
4	.502	.061	.441	87.9

[1] Shattered badly.

Balls exposed to laboratory conditions for 7 months, then placed in water at 60° C. for 23 days.

HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.494	0.399	0.095	19.2
2	.498	.406	.092	18.4
3	.502	.393	.109	21.7
4	.496	.384	.112	22.5

HEIGHT OF DROP, 24 INCHES.

1	0.505	0.330	0.175	34.6
2	.493	.321	.172	34.8
3	.498	.315	.183	36.7
4	.495	.318	.177	35.7

HEIGHT OF DROP, 36 INCHES.

1	0.490	0.236	0.254	51.8
2	.493	.290	.203	41.1
3	.492	.261	.231	46.9
4	.502	.258	.244	48.6

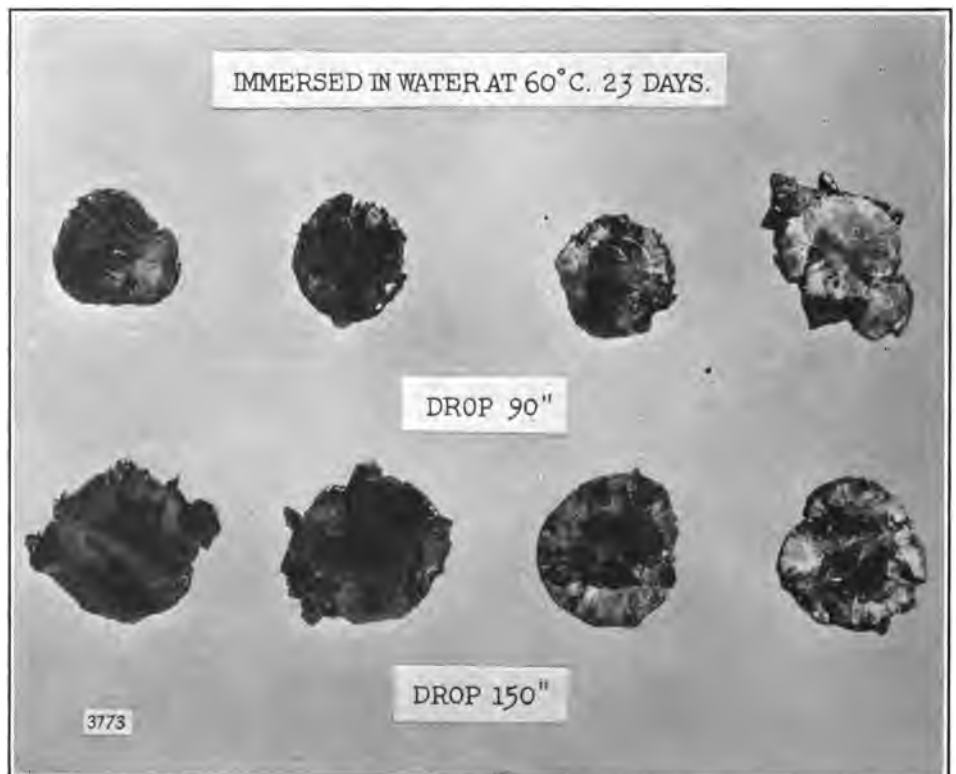
IMMERSED IN WATER AT 60°C. 23 DAYS.

DROP 12"

DROP 24"

3771

IMMERSED IN WATER AT 60°C. 23 DAYS.
DROP 36"
DROP 60"
3772


IMMERSED IN WATER AT 60°C. 23 DAYS.
DROP 90"
DROP 150"
3773

Balls exposed to laboratory conditions for 7 months, then placed in water at 60° C. for 23 days—Continued.

HEIGHT OF DROP, 60 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.500	0.194	0.306	61.2
2	.495	.173	.322	65.0
3	.507	.118	.389	76.5
4	.505	.190	.315	62.3

HEIGHT OF DROP, 90 INCHES.

1	0.502	0.117	0.385	76.6
2	.506	.144	.362	71.5
3	.504	.130	.374	74.2
4	.496	.069	.427	86.0

HEIGHT OF DROP, 150 INCHES.

1	0.488	0.077	0.411	84.2
2	.491	.076	.415	84.5
3	.490	.086	.404	82.4
4	.492	.090	.402	81.7

Balls exposed to laboratory conditions for 7 months, then placed in drying oven at 110° C. for 23 days.

HEIGHT OF DROP, 12 INCHES.

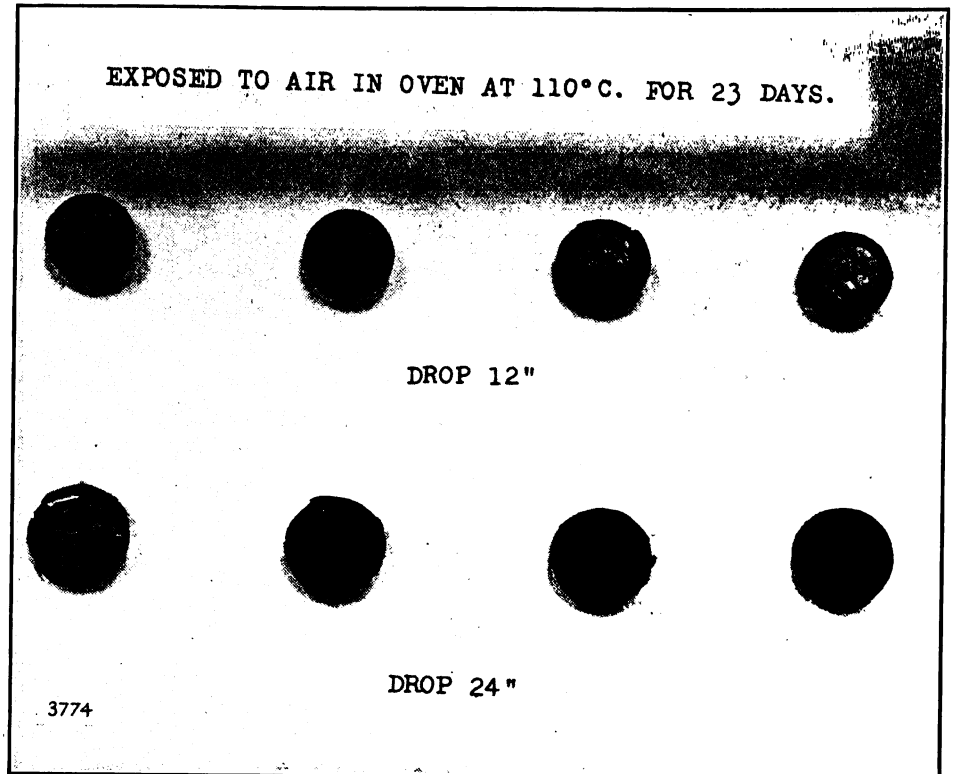
Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.494	0.333	0.161	32.6
2	.500	.345	.155	31.0
3	.497	.337	.160	32.2
4	.507	.350	.157	31.0

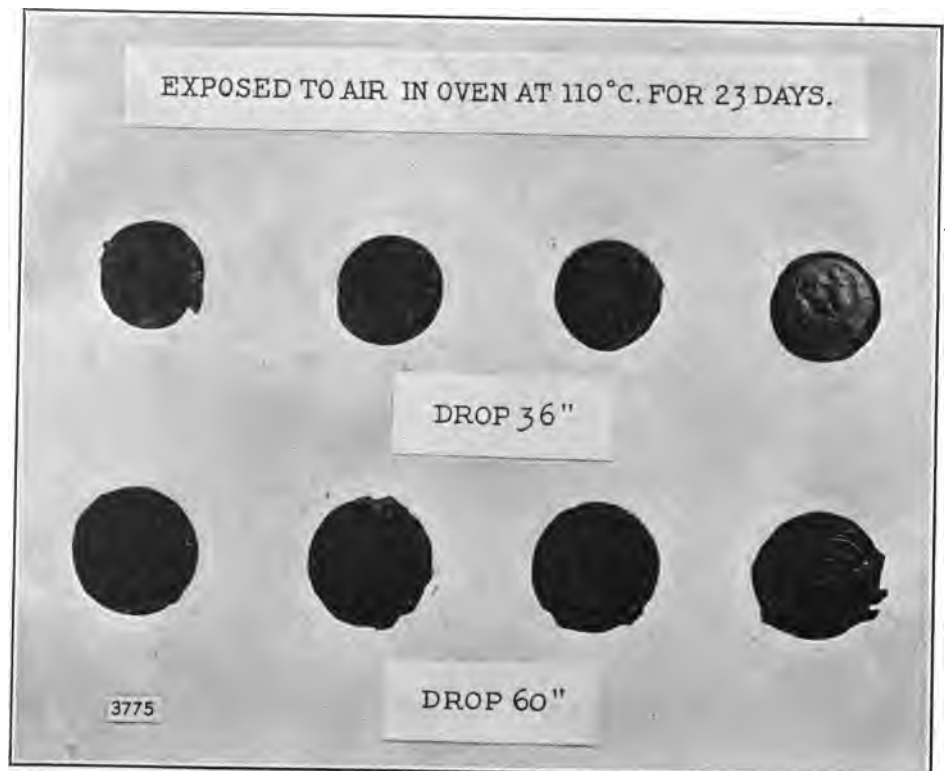
HEIGHT OF DROP, 24 INCHES.

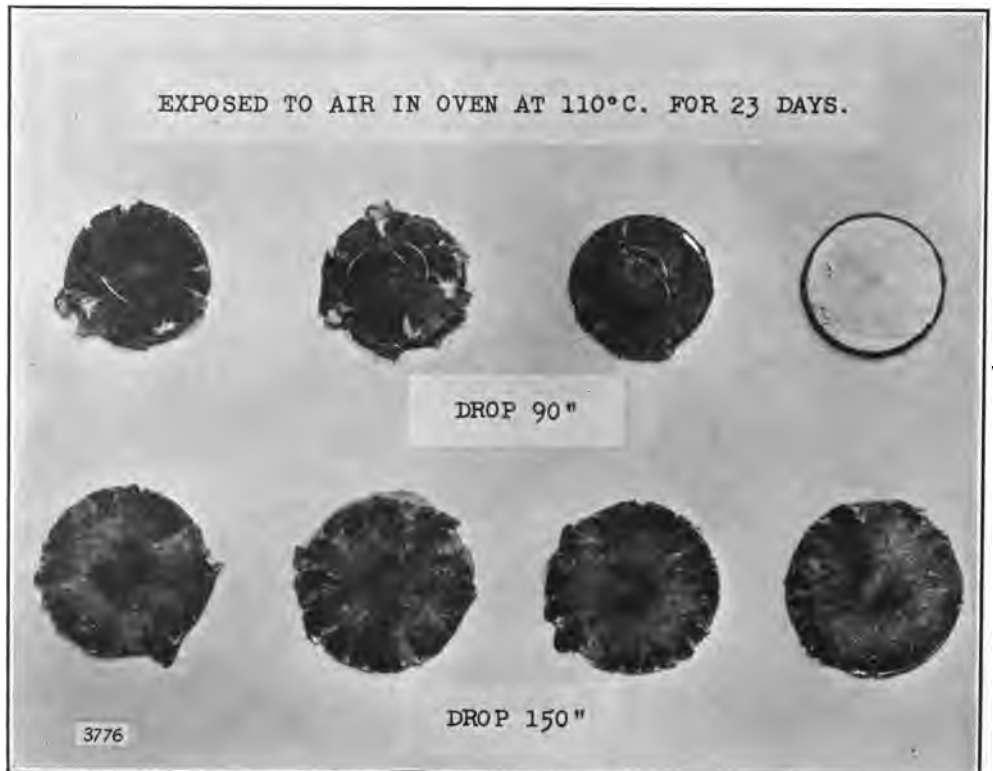
1	0.492	0.268	0.224	42.1
2	.503	.265	.238	47.3
3	.511	.272	.239	46.8
4	.493	.270	.223	45.2

HEIGHT OF DROP, 36 INCHES.

1	0.490	0.217	0.273	55.7
2	.490	.213	.277	56.5
3	.494	.215	.279	56.4
4	.493	.216	.277	56.1


EXPOSED TO AIR IN OVEN AT 110°C. FOR 23 DAYS.
DROP 12"
DROP 24"
3774


EXPOSED TO AIR IN OVEN AT 110°C. FOR 23 DAYS.
DROP 36"
DROP 60"
3775


EXPOSED TO AIR IN OVEN AT 110°C. FOR 23 DAYS.
DROP 90"
DROP 150"
3776

Balls exposed to laboratory conditions for 7 months, then placed in drying oven at 110° C. for 23 days—Continued.

HEIGHT OF DROP, 60 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.504	0.154	0.350	69.4
2	.500	.150	.350	70.0
3	.491	.149	.342	69.2
4	.494	.150	.344	69.5

HEIGHT OF DROP, 90 INCHES.

1	0.500	0.104	0.396	79.2
2	.503	.109	.394	78.3
3	.491	.110	.381	79.4
4	.502	.105	.397	79.1

HEIGHT OF DROP, 150 INCHES.

1	0.493	0.072	0.421	85.0
2	.494	.072	.422	84.8
3	.495	.075	.420	84.9
4	.492	.071	.421	85.4

Balls exposed to laboratory conditions for 7 months, then placed in 0.2 per cent solution of potassium chlorate for 23 days.

HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.497	[1] 0.326	0.171	34.4
2	.496	[1] .249	.247	49.9
3	.494	[1] .350	.144	29.1
4	.508	.381	.127	25.0

HEIGHT OF DROP, 24 INCHES.

1	0.500	0.306	0.194	38.8
2	.496	.222	.274	55.2
3	.494	.300	.194	39.5
4	.493	.317	.176	36.4

HEIGHT OF DROP, 36 INCHES.

1	0.492	0.297	0.195	39.7
2	.493	.222	.271	55.0
3	.499	.193	.306	61.3
4	.494	.257	.237	48.0

[1] Shattered badly.

100-1

IMMERSED IN DILUTE POTASSIUM CHLORATE SOLUTION 23 DAYS.

DROP 36"

3778

DROP 60"

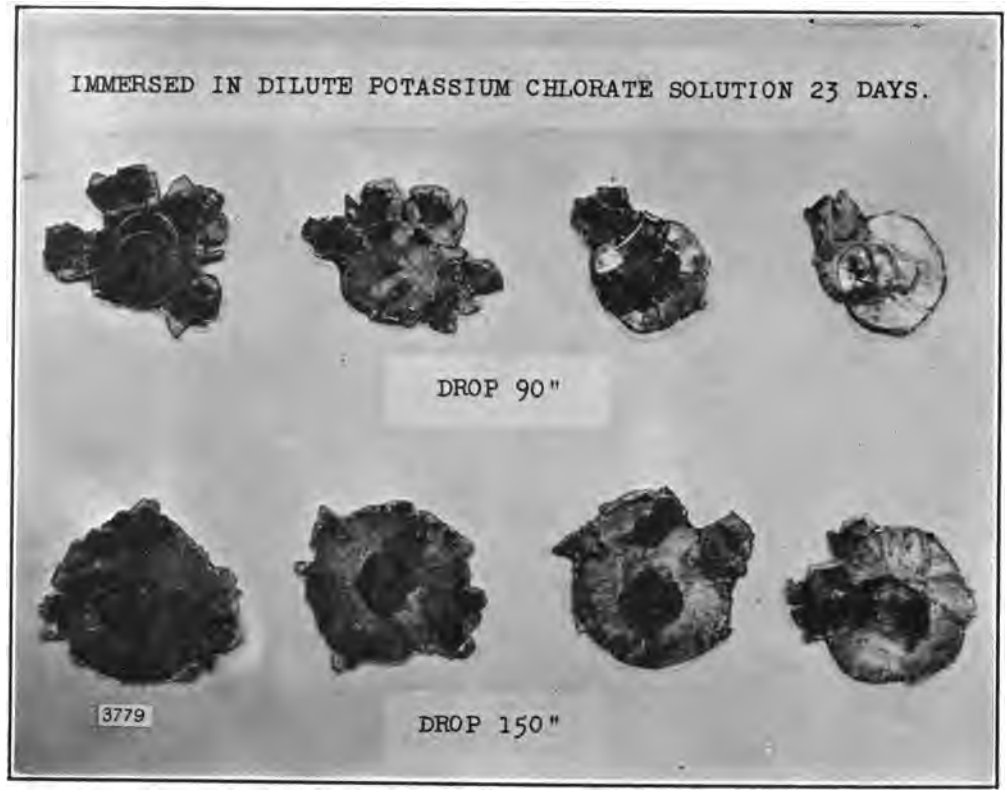
100-2

IMMERSED IN DILUTE POTASSIUM CHLORATE SOLUTION 23 DAYS.

DROP 12"

3777

DROP 24"


IMMERSED IN DILUTE POTASSIUM CHLORATE SOLUTION 23 DAYS.
DROP 90"
3779
DROP 150"

Balls exposed to laboratory conditions for 7 months, then placed in 0.2 per cent solution of potassium chlorate for 23 days—Continued.

HEIGHT OF DROP, 60 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.503	0.110	0.393	78.1
2	.501	.158	.343	68.4
3	.495	.117	.378	76.4
4	.494	.176	.318	64.4

HEIGHT OF DROP, 90 INCHES.

1	0.501	0.100	0.401	80.0
2	.498	.085	.415	83.2
3	.482	.114	.368	76.4
4	.497	.117	.380	76.4

HEIGHT OF DROP, 150 INCHES.

1	0.498	0.065	0.433	87.0
2	.488	.068	.420	86.0
3	.495	.070	.425	85.9
4	.498	.068	.430	86.3

Balls exposed to laboratory conditions for 7 months, then placed in 0.2 per cent solution of potassium permanganate for 23 days.

HEIGHT OF DROP, 12 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact(inch).	Reduction of diameter by impact (per cent).
1	0.496	0.372	0.124	25.0
2	.504	.190	.314	61.1
3	.495	.328	.167	33.7
4	.494	.377	.117	23.6

HEIGHT OF DROP, 24 INCHES.

1	0.493	0.286	0.207	41.0
2	.499	.281	.218	43.7
3	.491	.227	.264	53.7
4	.495	.235	.260	52.5

HEIGHT OF DROP, 36 INCHES.

1	0.495	0.178	0.317	64.0
2	.505	.141	.364	72.0
3	.493	.220	.273	55.3
4	.494	.168	.326	66.0

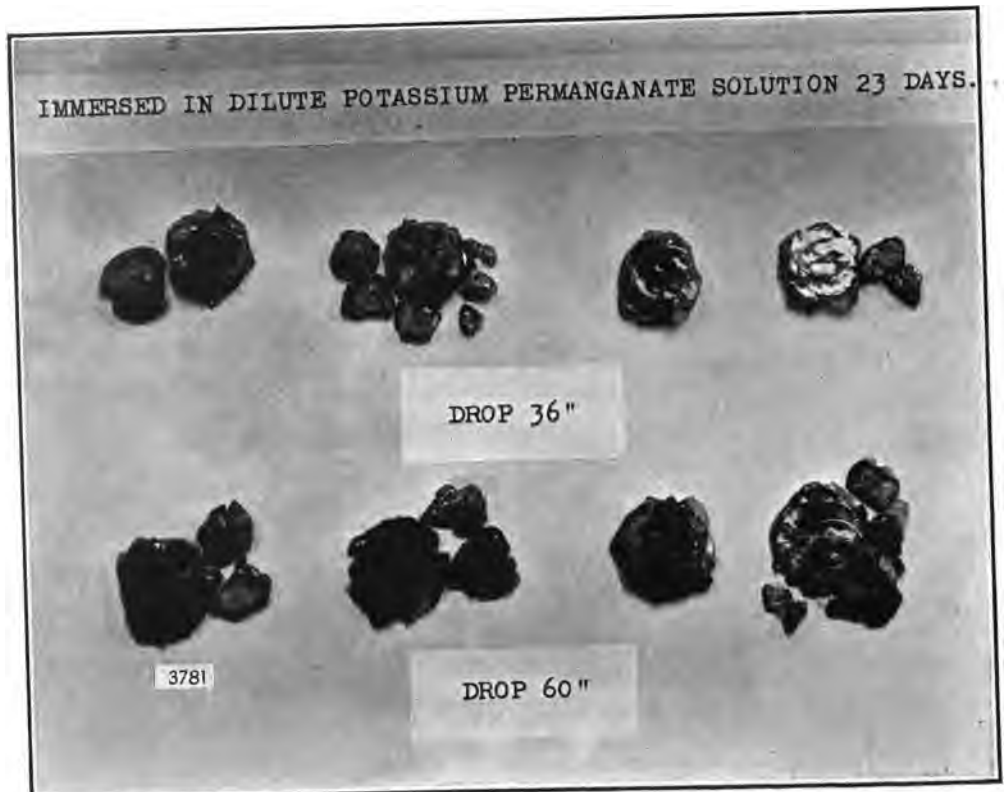
102-1

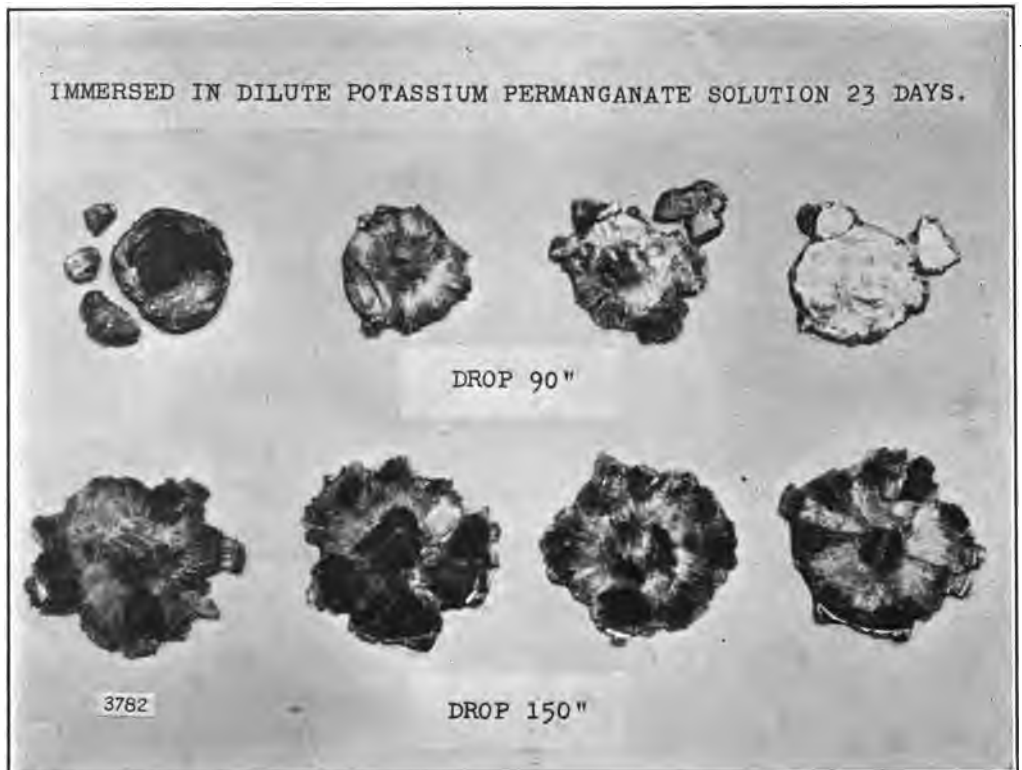
IMMERSED IN DILUTE POTASSIUM PERMANGANATE SOLUTION 23 DAYS.

DROP 12"

DROP 24"

3780


IMMERSED IN DILUTE POTASSIUM PERMANGANATE SOLUTION 23 DAYS.
DROP 36"
3781
DROP 60"


IMMERSED IN DILUTE POTASSIUM PERMANGANATE SOLUTION 23 DAYS.
DROP 90"
3782
DROP 150"

Balls exposed to laboratory conditions for 7 months, then placed in 0.2 per cent solution of potassium permanganate for 23 days—Continued.

HEIGHT OF DROP, 60 INCHES.

Specimen.	Diameter before impact (inch).	Diameter after impact (inch).	Reduction of diameter by impact (inch).	Reduction of diameter by impact (per cent).
1	0.505	0.136	0.369	73.0
2	.500	.097	.403	80.6
3	.492	.139	.253	51.5
4	.505	.087	.418	82.8

HEIGHT OF DROP, 90 INCHES.

1	0.496	0.100	0.396	79.8
2	.508	.060	.448	88.2
3	.504	.078	.426	84.4
4	.503	.065	.438	87.0

HEIGHT OF DROP, 150 INCHES.

1	0.495	0.058	0.437	88.3
2	.493	.060	.433	87.7
3	.503	.061	.442	87.7
4	.500	.057	.443	88.6

URANIUM STEEL.

OBJECT.

The object of this investigation was to study the properties of uranium steel in which uranium was the special alloying element.

MATERIAL.

The steel used was furnished by a private concern, and was supplied in the form of three bars, each 5 inches by 1¼ inches by 1¼ inches.

CONCLUSIONS.

The presence of approximately 0.50 per cent of uranium has apparently little effect upon the location of the critical point, and although the physical tests taken from this material in the forged and treated states were very good, no remarkable physical properties were exhibited. The Charpy qualities were very low both in the forged and treated condition.

EXPERIMENTAL.

The chemical analysis of this material was as follows:

	Per cent.
Carbon	0.64
Manganese	.30
Silicon	.207
Sulphur	Trace.
Phosphorus	.016
Uranium	.52

Critical point determinations were made on this material and the point on heating was located at 770° C. and on cooling at 700° C. The heating and cooling curves are shown on the graph, page 106.

Two of the bars were selected for heat treatment, and 800° C. was chosen as the quenching temperature, the bars being held at this temperature 30 minutes before being quenched in oil. One of the bars was drawn 30 minutes at 400° C., and the other 30 minutes at 600° C. One tensile and two Charpy tests were taken from each of the bars. The results of the physical tests are tabulated below.

Marks.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness.	Charpy test (foot-pounds per square inch).	Treatment.
17-1	64,000	124,500	12.0	20.5	241	13.2	As received.
17-3	97,000	149,000	16.0	49.1	311	28.3	Quenched at 800° C., drawn at 400° C.
17-2	81,000	131,500	18.5	46.2	262	25.3	Quenched at 800° C., drawn at 600° C.

The stress-strain diagrams are shown on the graph on page 107.

The results of the physical tests show nothing abnormal and are closely comparable to a straight carbon steel of approximately the same composition after the same treatment. The Charpy results obtained were very low and there is no apparent reason, judging from the elongation and contraction given in the tensile tests, why this should be so. The brittleness observed in this material may not be due to the presence of uranium, but as this is the only special alloying element, the inference would be that uranium was far from being beneficial.

As the idea has been advanced that uranium would be a desirable alloying element for the prevention of erosion in guns, the fact that the uranium steel examined has a very low Charpy impact figure would certainly detract from its usefulness in gun construction, even though its resistance to erosion might be great. For purposes of comparison it can be stated that a plain carbon steel with approximately the same composition as the uranium steel examined would give a shock test after quenching and drawing at 400° C. of at least 100 foot-pounds per square inch.

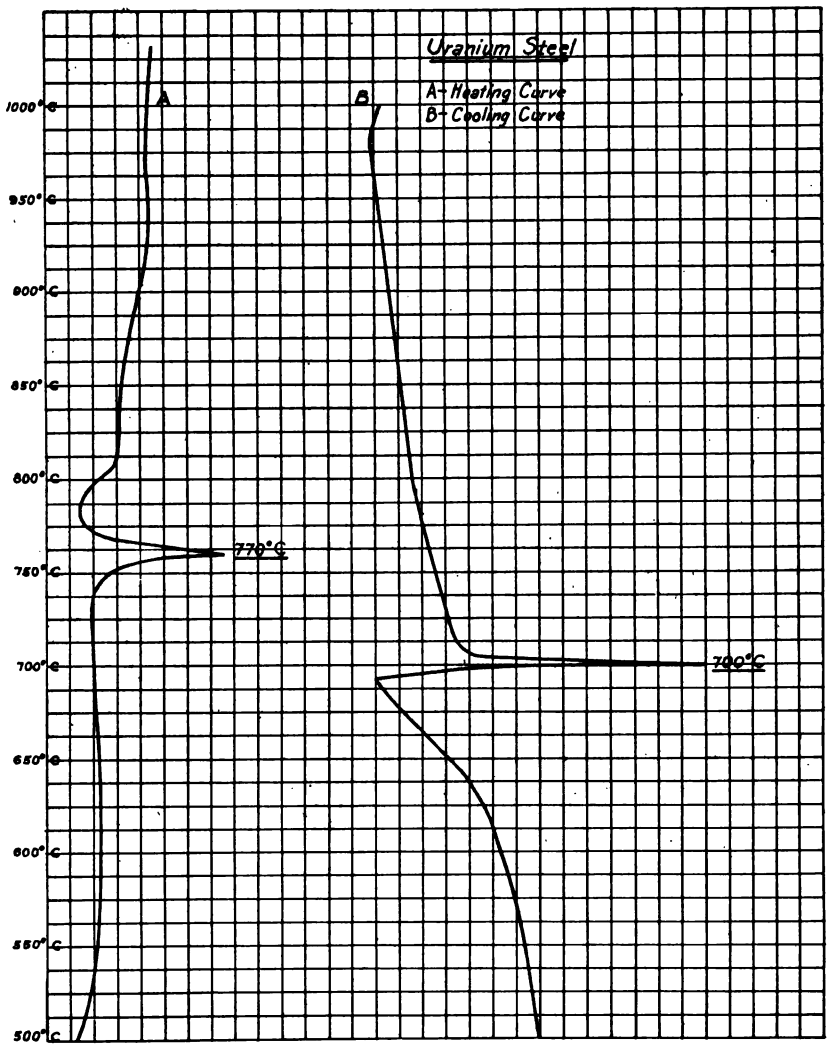
Micrographs Nos. 3556 and 3557, at 50 and 500 X respectively, represent the structure of the steel as received, presumably in the forged and unannealed condition.

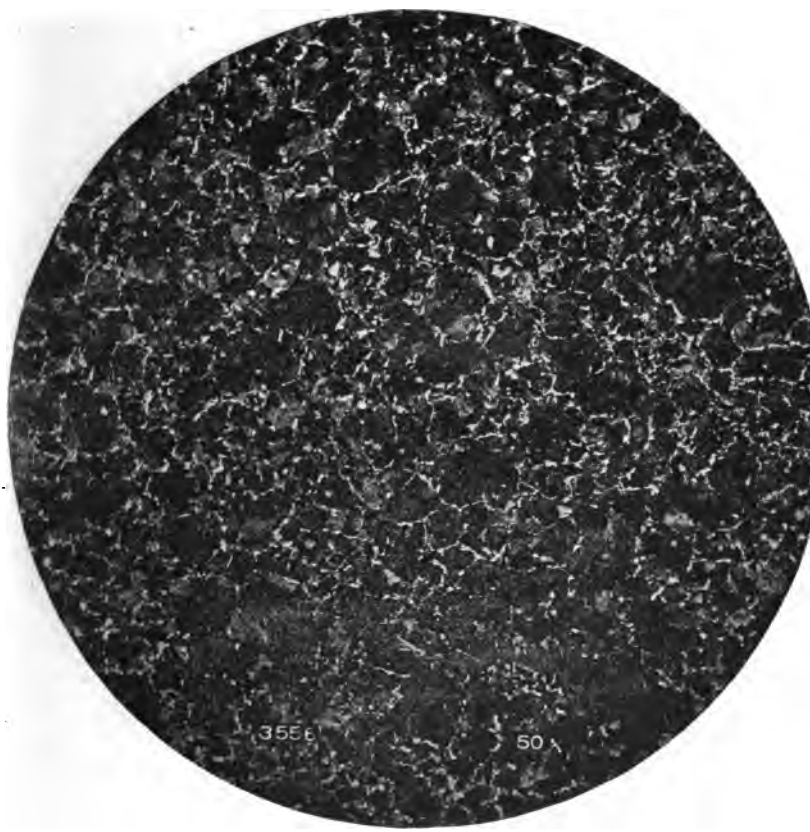
Micrograph No. 3557, at 500 X, shows poorly defined pearlite intermingled with sorbite.

Micrographs Nos. 3562 and 3563, at 50 and 500 X rexpectively, show the structure after heating to 1,000° C., followed by slow cooling in the furnace. The structure is distinctly pearlitic and the low power micrograph, No 3562, shows a decided tendency for this steel to assume a banded structure. It may be possible that the low Charpy tests obtained were due to this phenomenon, although it is not apparent in the microstructures of the quenched and drawn samples.

Micrographs Nos. 3560 and 3561, at 50 and 500 X respectively, show the structure after quenching from 800° C. and drawing at 400° C. The structure is very fine and the high power micrograph, No. 3561, shows troostite and sorbite with very little free ferrite.

Micrographs Nos. 3558 and 3559, at 50 and 500 X respectively, show the structure of the steel after quenching at 800° C. and drawing at 600° C. Small areas of free ferrite are also evident in this structure.


Uranium Steel
A-Heating Curve
B-Cooling Curve
A
B
1000°C
950°C
900°C
850°C
800°C
750°C
700°C
650°C
600°C
550°C
500°C
770°C
700°C



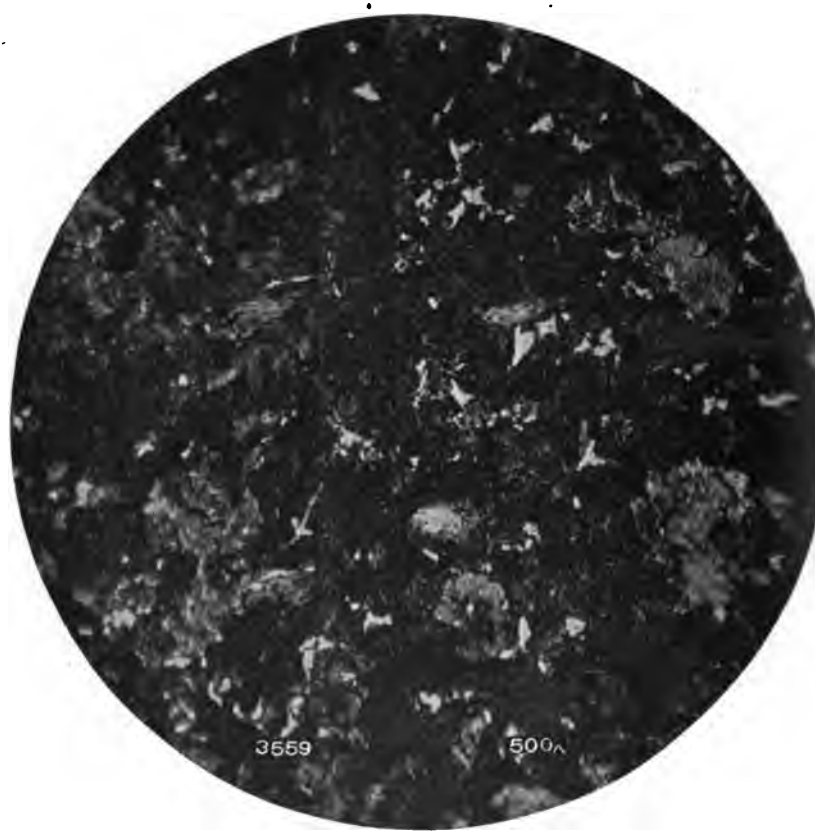
MICROGRAPH NO. 3556. 50 X. STRUCTURE OF STEEL AS RECEIVED.

107-1

MICROGRAPH NO. 3557. 500 X. STRUCTURE OF STEEL AS RECEIVED.

MICROGRAPH NO. 3558. 50 X. QUENCHED AT 800° C. AND DRAWN AT 600° C.

107-3



MICROGRAPH NO. 3559. 500 X. QUENCHED AT 800° C. AND DRAWN AT 600° C.

MICROGRAPH NO. 3560. 50 X. QUENCHED FROM 800° C. AND DRAWN AT 400° C.

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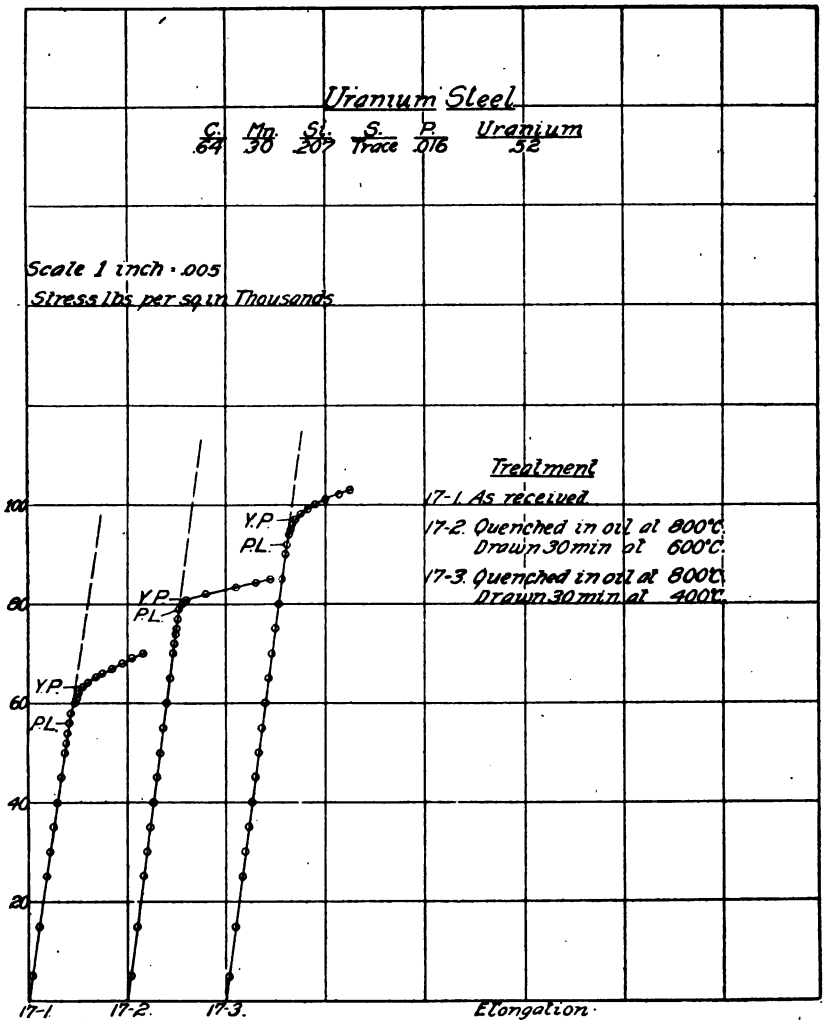
MICROGRAPH NO. 3561. 500 X. QUENCHED FROM 800° C. AND DRAWN AT 400° C.

MICROGRAPH NO. 3562. 50 X. HEATED TO 1,000° C., FOLLOWED BY SLOW COOLING IN THE FURNACE.

MICROGRAPH NO. 3563. 500 X. HEATED TO 1,000° C., FOLLOWED BY SLOW COOLING IN THE FURNACE.


Uranium Steel.
C. Mn. Si. S. P. Uranium
.64 .30 .207 Trace .016 .52
Scale 1 inch = .005
Stress lbs per sq in Thousands
Treatment
17-1. As received
17-2. Quenched in oil at 800°C.
Drawn 30 min at 600°C.
17-3. Quenched in oil at 800°C.
Drawn 30 min at 400°C.
100
80
60
40
20
Y.P.
P.L.
Y.P.
P.L.
Y.P.
P.L.
17-1
17-2.
17-3.
Elongation.

EXAMINATION OF BROKEN BOLT HEAD.

OBJECT.

The object of this investigation was to determine the nature of the metal used in the construction of a 1¼-inch tap bolt for 6-inch disappearing carriage, Model 1905 MLL, No. 22. The head of this bolt was twisted off while assembling the left chassis to the racer.

CONCLUSIONS.

The failure in question was due to poor material; excessive segregation was present and the phosphorus and sulphur contents both were high.

EXPERIMENTAL.

An inspection of the records shows that the material was issued from an accumulation of stock obtained prior to the adoption of present methods and specifications now followed in securing machinery steel and bolt stock.

A section was taken vertically through the bolthead for microexamination. This specimen was etched with Stead's reagent with most interesting results. The outside portions of the bolt were covered with a thick deposit of copper and the interior showed many folds. The following photograph at approximately 2½ diameters clearly illustrates the conditions present.

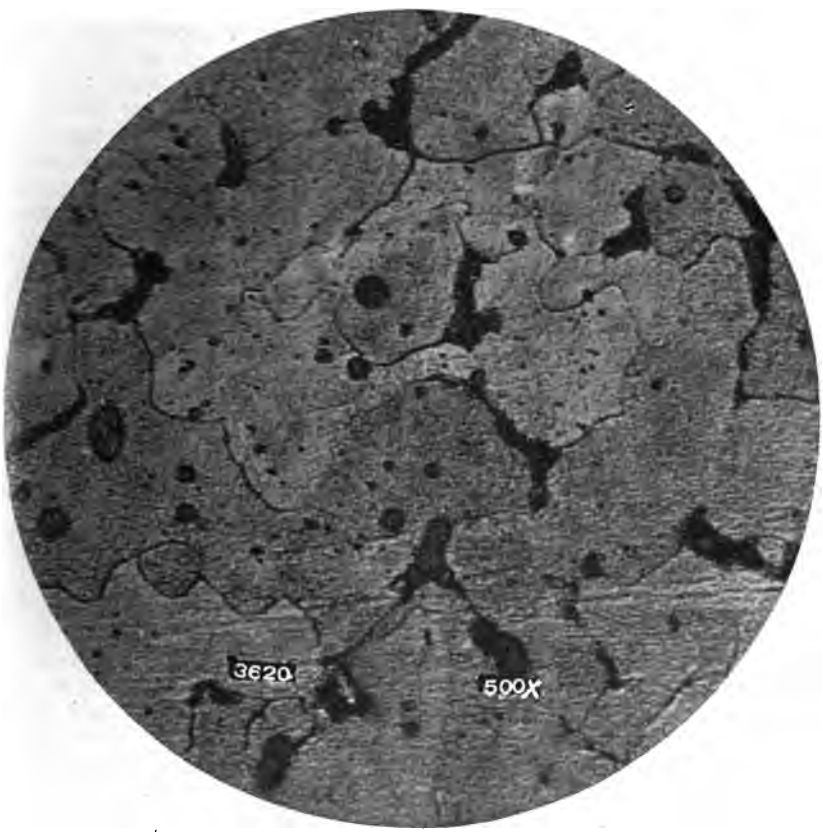
FRACTURE.

A layer appearing white in the photograph is the outside of the bolthead on which the copper was deposited with great rapidity. This layer thinned out on the top of the head as shown above. These conditions were present also on the other half of the bolt which was subsequently cut up for chemical analysis.

A micrograph at 500 diameters, No. 3619, was taken on the band at the edge of the specimen after repolishing and etching with nitric acid. The structure shows almost pure ferrite, with very few inclusions.

108–1

108-2



109-1

109-2

The interior structure is shown in micrograph No. 3620, at 500 diameters. Small areas of sorbite are present and also many inclusions which occur both in the grains and at the junction lines. Both modes of occurrence are clearly shown in the micrograph (No. 3620).

Micrograph No. 3618 at 50 diameters illustrates the structure at the junction of the outside and inside layers. The outside layer is practically free of carbon and inclusions, whereas the interior contains many inclusions and small sorbite areas.

An inspection of the sample also showed many small checks and cracks in the vicinity of the fracture. Some of these appearing as dark lines are evident in photograph No. 3624, page 108.

As the microscopic examination revealed on the outside of the bolthead a band which had a different composition from the interior, two chemical samples were taken, one being milled off the outside to a depth of one-eighth inch and the second from the interior of the specimen. The results were as follows:—

	C.	Mn.	Si.	S.	P.
Inside	0.102	0.30	0.0066	0.090	0.131
Outside	.086	.....	.....	.048	.074

The outside sample was lower in carbon, phosphorus, and sulphur than the inside sample, and furthermore, the difference was probably greater than is apparent from the analysis, as the carbon, by microexamination, was nearly zero in the outside layer, whereas the chemical analysis shows 0.086 per cent. The natural inference would be that in milling off the outside sample the cut extended through this layer into the interior. Regardless of this, a decided difference was shown between the outside and inside samples, and the usefulness of Stead's reagent in showing segregation was certainly established in this case.

It is interesting to note in conclusion, that the outside layer, which was low in carbon, phosphorus, and sulphur, extended over a portion of the top of the bolt in such a manner that one is led to conclude that the original bar from which the bolts were made was itself surrounded with a layer different in composition from the interior. This condition can be traced back to the original ingot in which an insufficient crop would have left a portion containing a segregated center surrounded by relatively pure and clean metal. The operations of rolling would have resulted in the conditions observed above.

As to the direct cause of failure of the bolt in question, ample cause exists. In forming the head in the bolt machine, incipient cracks may have been formed, due to red shortness caused by high sulphur and low manganese. The appearance of the polished vertical section would indicate that this was at least a contributary cause.

The phosphorus content is in itself sufficiently high to give rise to cold shortness, or in other words, brittleness at ordinary temperatures.

EXAMINATION OF PISTOL BARREL WHICH BURST IN SERVICE.

This barrel, on receipt at this arsenal, showed a very coarse fracture. The portion of the barrel examined was approximately 4 inches long, the fracture extending throughout its length.

CONCLUSIONS.

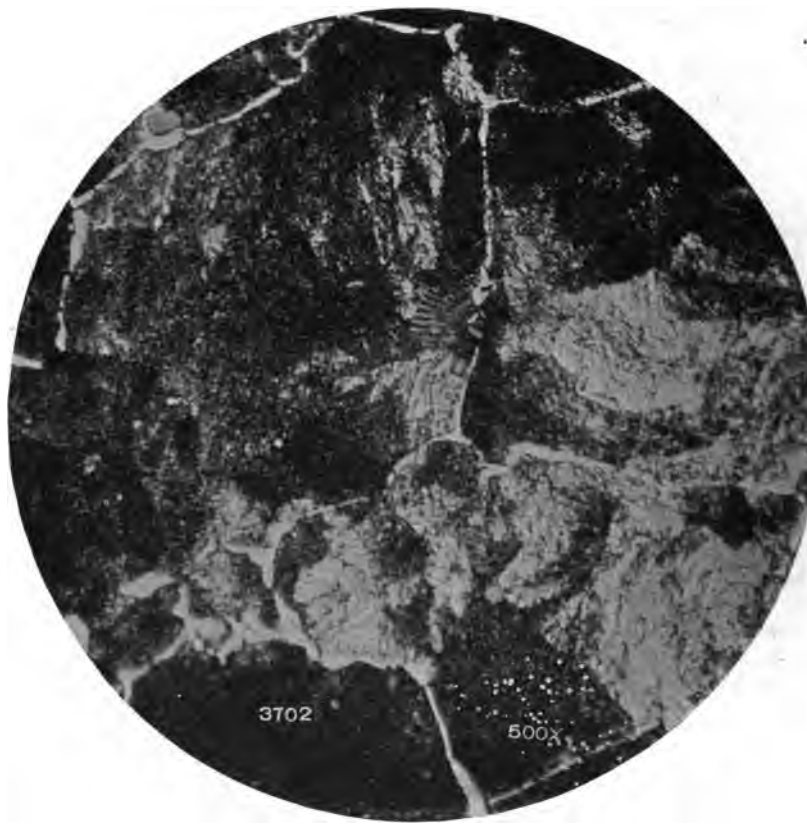
The structure found on microscopical examination was very coarse, and as considerable pearlite was present, it must be concluded that the material had cooled slowly from a relatively high temperature without being subjected to mechanical work.

The longitudinal specimen also shows a tendency to be streaked, but the amount of slag or other inclusions present was very small. If this barrel had received no treatment subsequent to the forging operation, it would be inferred that the material had been heated to too high a temperature for forging, and consequently the finishing temperature was also too high. As a result, the coarse-grained structure was developed by cooling undisturbed from a temperature considerably above the critical range.

Although the relation between the resistance to shock and grain size in a pearlitic steel can not be stated definitely at this time, data has been obtained on the Charpy impact machine which indicates that a large-grained pearlitic steel has much less resistance to shock than a small-grained pearlitic steel, whereas the hardness as determined either by the Brinell or scleroscope test might be identical.

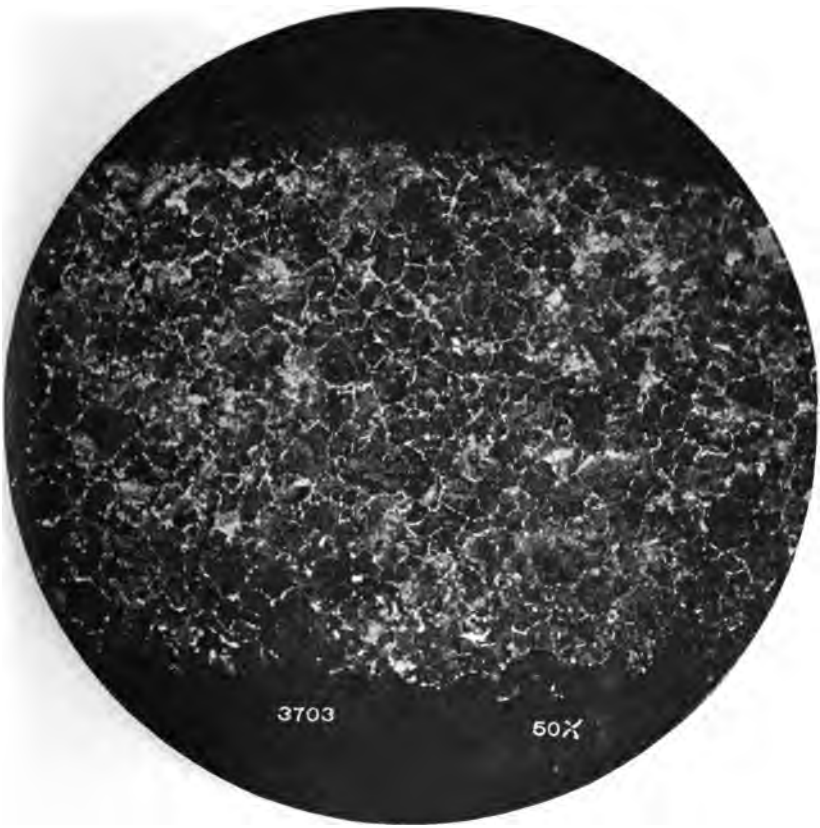
MICROGRAPH NO. 3701.

Cross section of barrel at 500 diameters. The structure is composed of pearlite and sorbite.



MICROGRAPH No. 3702.

Longitudinal section of barrel at 500 diameters. Structure is pearlitic with a slight amount of sorbite. Relative freedom from all metallic inclusions is to be noted.



MICROGRAPH NO. 3703.

Cross section of barrel at 50 diameters.

MICROGRAPH NO. 3704.

Longitudinal section of the barrel at 50 diameters. The streaked tendency is to be noted.

III-1

31082—18——13

111-2

EXAMINATION OF CEMENTED WIRE NAIL.

OBJECT.

The object of this investigation was to determine the merits of the process of converting low-grade iron into high-grade steel. It was claimed by the inventor of this process that a newly invented or discovered process was being submitted for the conversion of iron of low grade into high-grade steel at a minimum of expense through a chemical process.

CONCLUSIONS.

The wire nail submitted was casehardened and quenched. If any merit exists in the process, or any new discovery is involved, it can consist only in the nature of the compound used for cementation.

The conversion of wrought iron or low-carbon steel into a material of a higher carbon content by heating in contact with a carbonaceous material has been known for many years. The cementation process of making steel is one of the oldest methods employed and is now practically obsolete. The reasons that this process has given way to others for the production of high-carbon steel are, first, no advantages were apparent in introducing carbon by this method in any case where it was necessary to remelt the material; second, the cost of steel made by the cementation process was greater than that of steel made by the crucible process. The greatest use of the cementation process to-day is in the production of casehardened articles.

It was further claimed by the inventors that the cost per pound of converting low-grade iron into steel is about 1 cent for the chemicals used. This would amount to $20 per ton, the cost of fuel and labor not included. The cost of high-grade steel which is quoted in this letter is entirely out of reason, even at the present market, high-speed steels selling for approximately $2.50 per pound, and that is probably the highest priced steel on the market.

A common misunderstanding seems to exist in the minds of the inventors of this process that simply because the material is low carbon, it is by necessity a low grade or cheap material. Nothing can be farther from the truth, as a difference in cost between an open-hearth steel of 0.10 per cent carbon and 0.50 per cent carbon is negligible when compared to the cost of converting the 0.10 per cent carbon steel into a 0.50 per cent carbon steel by the cementation process.

EXPERIMENTAL.

Photomicrograph No. 3709 shows the structure of this nail at 500 diameters in a portion close to the circumference of the nail. Martensite is clearly present. The general structure of the nail is as follows: center, soft, having the typical structure of a quenched low-carbon steel. The soft core is surrounded by a circle of troostitic material, and in turn this was surrounded by a layer of martensitic material. This, as stated previously, is characteristic of a casehardened and quenched article.

Photomicrograph No. 3708, at 50 diameters, shows the structure of the nail after it had been heated to 1,000° C. and slowly cooled. The low-carbon center is to be noted with the gradual increasing carbon content toward the circumference of the nail.

SUPPLEMENTARY REPORT ON THE EXAMINATION OF CEMENTED WIRE NAIL.

The samples reported herein were submitted to the laboratory by Col. C. B. Wheeler, and consisted of two nails which had been formed into knives, and a third nail, the point of which resembled a chisel.

CONCLUSIONS.

The examination of the samples submitted offers no additional evidence which would cause a reversal of the conclusions arrived at in the previous experimental report on the subject. The inventors have a compound which undoubtedly is yielding them an exceedingly high carbon case. The cost of the cementation process for producing iron and steel is very high, and the inventors' estimate of 1 cent a pound, or $20 a ton, for the chemicals employed would show at a glance that steel made by their process could not compete with steel made in the open-hearth or converter process.

It is further evident that tools such as those submitted would not stand up in service as well as the lower carbon tool of similar composition in other respects.

The inventor's process might have some practical application as a casehardening proposition, but as the only means available to this laboratory in determining this point is by the samples received, this question could not be definitely answered. It can be stated, however, that the samples examined had entirely too high a carbon content in the case for any properly casehardened article.

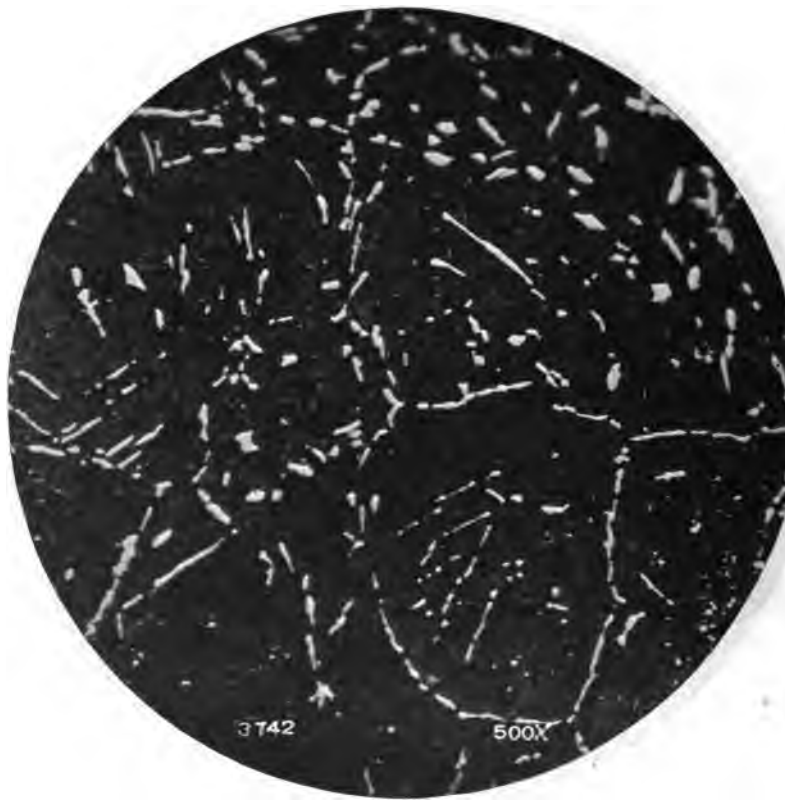
EXPERIMENTAL.

It was stated in the pamphlet submitted with these nails that the steel made by this process would compare with any high-speed steel on the market, not excepting vanadium, tungsten, Jessup, or any other make. One of the blades, which is very hard as determined by the file test, was annealed at 350° C. for a few minutes, after which it was readily attacked by the file. Any properly heat-treated high-speed steel would not be softened by this operation.

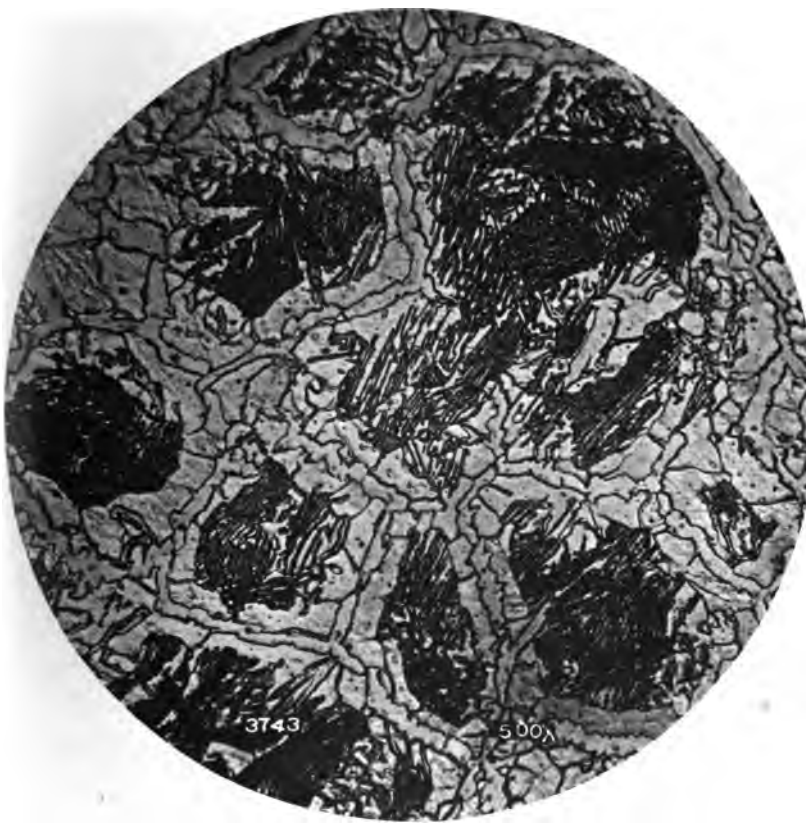
Samples from the two nails which had been formed into knives were annealed at 1,000° C. to obtain the normal structure. Micrograph No. 3741, facing this page, clearly indicates that carbon had been introduced into this nail by the cementation process, and the carbon content decreases from the outside inward. The central portion of the nail was apparently 0.35 to 0.40 carbon, and this zone is bound by a eutectic layer outside of which is another layer very high in carbon and with much excess cementite.

Micrograph No. 3742, facing this page, clearly indicates the structure at the outer portion of one of the nails as received and in the hardened condition. The matrix consists of troostite and

112-1



112-2



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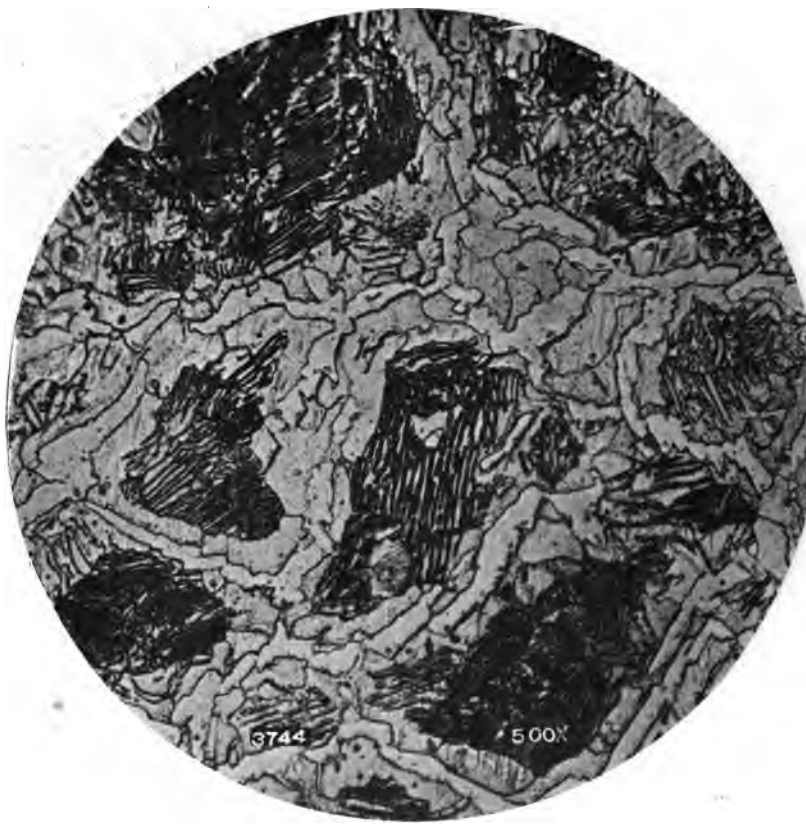


113–2

113-3

113-4

martensite and a network of excess cementite is present. This is very undesirable in any casehardened article, as it tends to brittleness and consequent spalling off of the case.

Micrographs No. 3743 and No. 3744 were taken in the outer portion of one of the nails after it had been heated to 1,000° C. and slowly cooled. These structures are of considerable scientific interest, although they show nothing which has not previously been encountered. A heavy network of cementite is present, and associated with this is free ferrite, the centers of the grains being pearlitic. It was held at one time that the coexistence of free cementite and free ferrite was impossible, but this has long since been proven false.

The specimen shown in micrograph No. 3744 was repolished and etched with sodium picrate. This etching attack darkens the cementite, leaving the ferrite bright. Micrograph No. 3745 shows the resulting structure. The heavy network of cementite is apparent, next to which occurs an almost continuous network of ferrite, and the nucleus of the grain is composed of pearlite. Their mode of occurrence would suggest the following relative stages of the constituents. The cementite separates first, this separation proceeding until the austenite becomes supersaturated with ferrite, the ferrite then separates until the eutectoid composition is reached and pearlite forms.

The nail which had been formed into a tool resembling a chisel was polished and photographed (3746) at 500 diameters as received. The cementite was in the spheroidized condition. A composite chemical sample was obtained from two of the nails. The annealed samples were so exceedingly brittle that sufficient chips could be obtained to determine carbon only. The results were as follows:—

Carbon, 1.50 per cent.

EXAMINATION OF CAST STEEL.

MATERIAL.

The material examined consisted of the ends of three test specimens marked, respectively, "A3," "A14" and "A15." These specimens were cut from the coupons representing the heats in question.

CONCLUSIONS.

Many of the castings examined were spongy and full of blow holes. The lack of ductility in the test specimens was due to an almost continuous network of slag inclusions around the original austenite crystals. This network can not be broken up by heat treatment.

The conditions observed were probably due to "cold blows" in the converter.

EXPERIMENTAL.

The physical properties of the three specimens are tabulated below.

Marks.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent).	Contraction of area (per cent).	Remarks.
A3	51,500	86,500	7.5	13.3	Rejected.
A14	52,500	85,500	9.5	9.5	Do.
A15	45,400	85,300	18.0	23.2	Accepted.

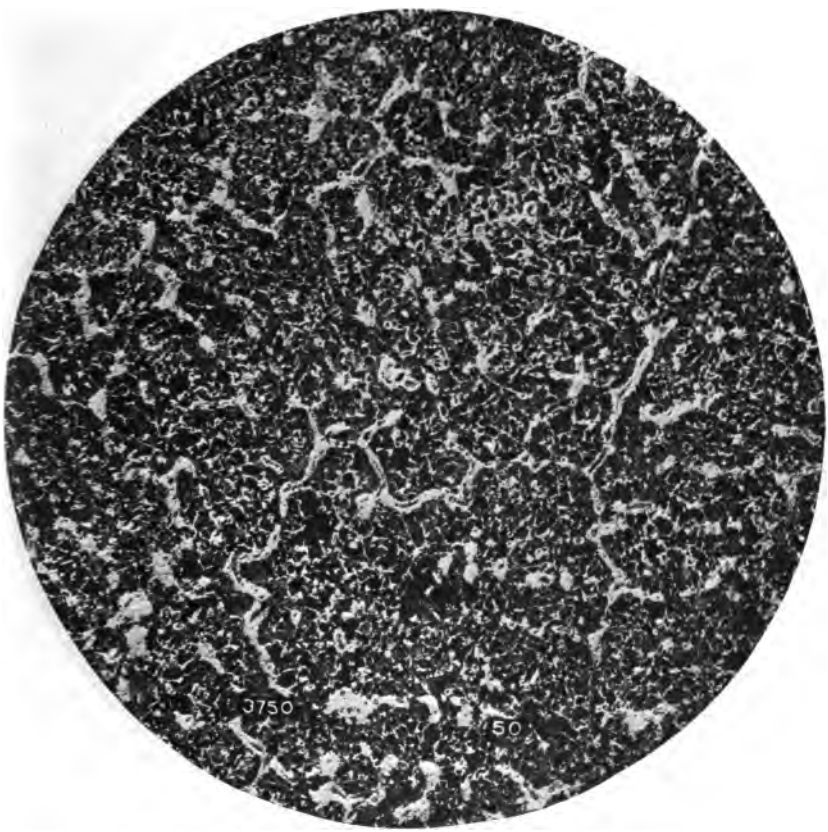
Carbon and manganese determinations were made on the three samples with the following results:

Marks.	C.	Mn.
A3	0.43	0.72
A14	.42	.72
A15	.426	.52

A microscopic examination was made on the base of the tensile specimens. Micrograph No. 3750, at 50 diameters, shows the structure of A3. Many slag inclusions in the ferrite areas are plainly visible. This is further illustrated in micrograph No. 3751 of the same specimen at 500 diameters.

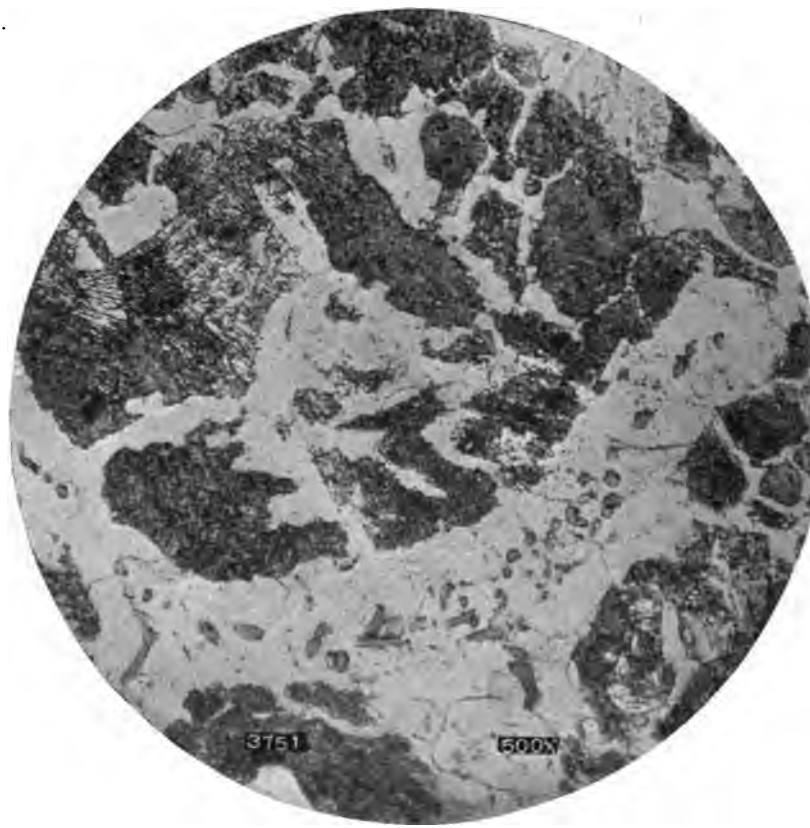
Micrographs No. 3752 and No. 3753 at 50 and 500 diameters, respectively, of specimen A14 reveal the same condition as was found in A15.

Micrograph No. 3754, at 50 diameters, from specimen A15, which passed the required physical tests, shows a ferrite network practically free of slag inclusions.



MICROGRAPH NO. 3750.

A3. Magnified 50 diameters. Shows slag in ferrite. The original austenite crystals are outlined. by a ferrite network containing a great deal of slag.



MICROGRAPH NO. 3751.

A3. Magnified 500 diameters. Shows slag in ferrite.

MICROGRAPH NO. 3752.

A14. Magnified 50 diameters. Shows slag in ferrite.

MICROGRAPH NO. 3753.

A14. Magnified 500 diameters. Shows slag in ferrite.

MICROGRAPH NO. 3754. A15 AT 50 X.

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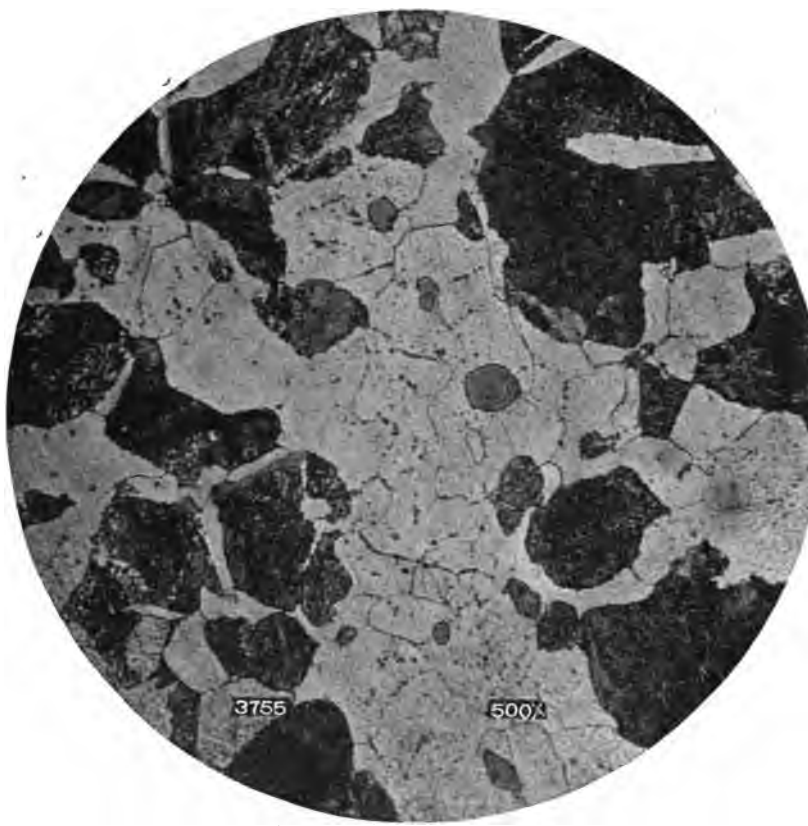


MICROGRAPH NO. 3755. A15 AT 500 DIAMETERS, SHOWING ONLY AN OCCASIONAL INCLUSION.

All the slag included in this specimen is in the form of rounded particles found here and there, which do not materially break up the continuity of the metal, as was the case in A3 and A14. This is illustrated in micrograph No. 3755, at 500 diameters, shown on the opposite page.

The annealing temperature might well have been carried higher for this specimen. An anneal at 925° to 950° C., followed by an air chill, would doubtless have removed all traces of the original austenite grains.

In samples A3 and A14 further annealing would have been useless, as the inclusions present in the form of an almost continuous network would destroy the ductility and produce brittleness.

EXAMINATION OF SEAT SPRING FOR REEL, MODEL 1909, NO. 46.

OBJECT.

The object of this investigation was to determine the cause of failure of seat spring for reel, Model of 1909, No. 46. This spring was forwarded for examination from the district ordnance office, Fort Bliss, Tex.

CONCLUSIONS.

Examination of the metal used in the construction of this part showed that the tempering operation after quenching had been insufficient. As a result, the material was too hard and brittle.

The specifications for this part call for "spring steel, tempered." This will permit the use of high-carbon stock to secure the necessary physical properties required of this part.

It would seem advisable to use a lower carbon steel in the construction of this spring. The following composition should after quenching in oil and drawing at 500° C. give an elastic limit of approximately 100,000 pounds.

Carbon, 0.45 to 0.55 per cent.
Manganese, 0.50 to 0.80 per cent.
Silicon, 0.15 to 0.35 per cent.
Sulphur, less than 0.05 per cent.
Phosphorus, less than 0.05 per cent.
Chromium, 1 to 1.25 per cent.
Vanadium, 0.15 to 0.25 per cent.

This is a typical composition only, and a variety of others could probably be used. The essential thing is to have the carbon at least less than 0.60 per cent in order to avoid brittleness.

If the carbon is lowered in this spring with its consequent lowering of the elastic limit to approximately 100,000 pounds, some slight changes of design might be necessary.

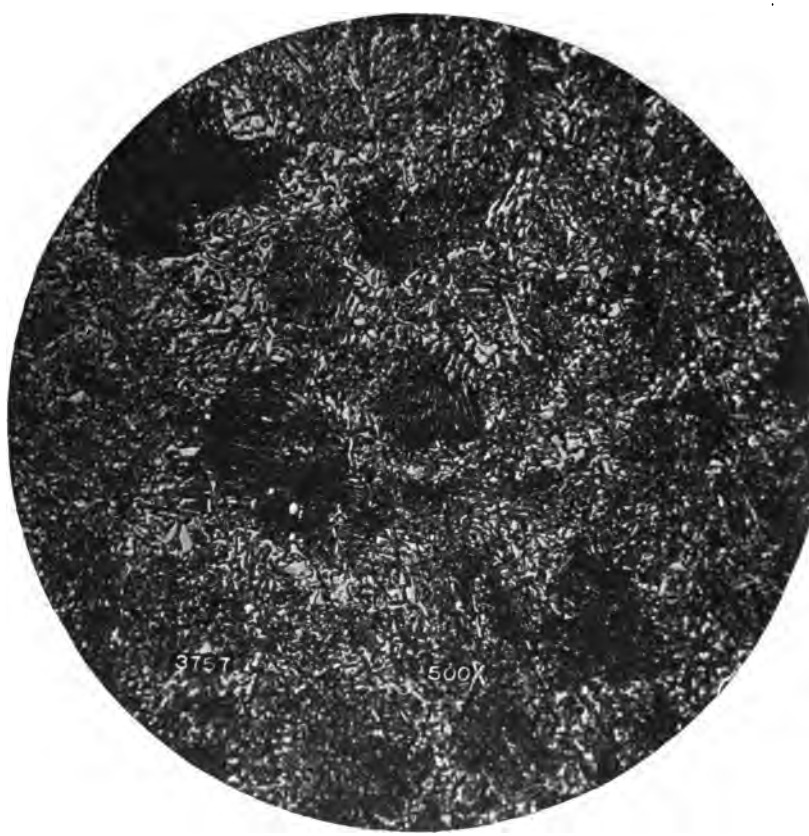
EXPERIMENTAL.

The Brinell hardness of the piece as received gave a value of 392.

A portion of the material was heated to 810° C. and quenched in water. The Brinell hardness was then 593. The piece was then drawn at successively higher temperatures until the hardness was the same as when received. The following results are shown:—

Condition:	Brinell hardness.
As received	392
After water quench from 810° C	593
After water quench from 810° C. and drawn 15 minutes at 400° C	421
After oil quench from 800° C	360

117-1



117-2

It would appear that the hardness of this piece could be obtained either by an oil quench followed by no tempering, or a water quench followed by tempering in the vicinity of 400° C.

The structure of the material as received, shown in micrograph No. 3756, at 500 diameters, is troosto-sorbitic. Micrograph No. 3757, at 500 diameters, shows the structure after heating to 1,000° and furnace cooled. The entire specimen is pearlitic, showing no excess constituents.

Chemical analysis made on a sample taken from the spring showed the carbon to be 0.926 per cent. As previously stated, this is considered too high where any conditions which are liable to produce shock are present.

COPPER ROTATING BANDS.

The material examined consisted of a sample ring made of pure copper, concerning which the following claims were made by the company submitting same:—

(1) That this ring was superior to a ring made from a drawn tube, due to the fact that it was rolled in the same direction as the periphery of the gun, which is the opposite of the way the grain of the metal is worked in a drawn tube.

(2) The copper driving band, rolled as above, would give as much as or more resistance than the cupro-nickel band and consequently will not shear off.

Further statements were also made by the manufacturers that the cupro-nickel band is also hard on the rifling of a gun.

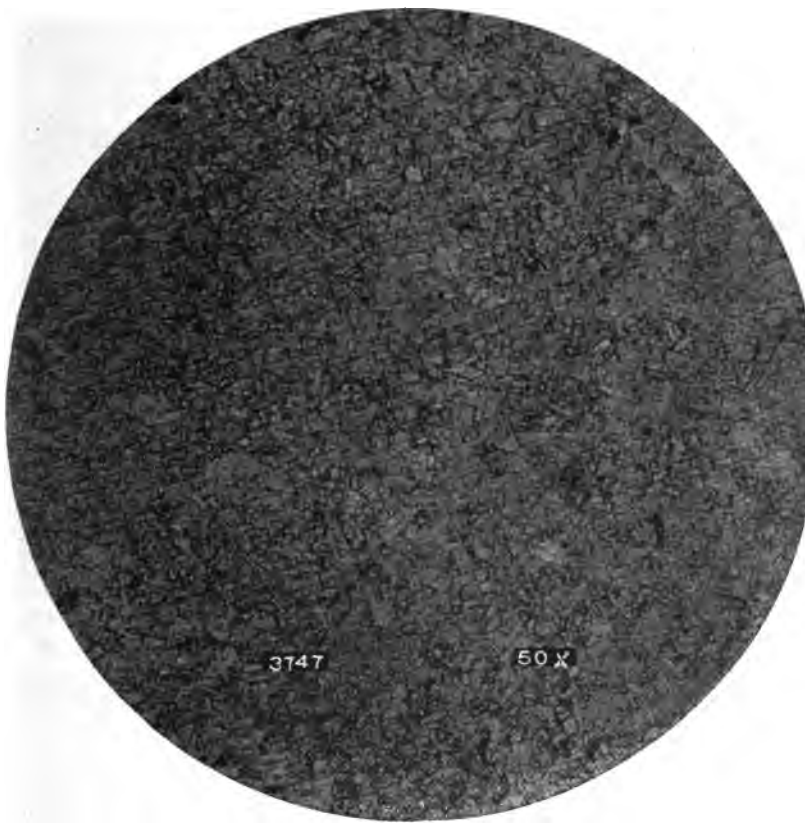
CONCLUSIONS.

The manufacture of driving bands by the method proposed by the manufacturer should produce material at least as good as that cut from drawn seamless tubing. The strength of the copper band made by their process will depend entirely upon the amount of reduction given to the material and the annealings to which it was subjected. There is no apparent reason why a band made by their process can not be so manufactured that it will satisfactorily meet the required specifications. The relative merits of the pure copper versus cupro-nickel band can not be considered an essential portion of this examination.

EXPERIMENTAL.

The copper band supplied by the manufacturer was 7.9 inches inside diameter and 8.65 inches outside diameter. The width was 1-15/16 inches.

A band cut from seamless tubing, such as is used in current manufacture, was taken for comparison. This band was 5.95 inches inside diameter, 6.77 inches outside diameter, and 1-15/16 inches wide. Both bands were cut and straightened cold, forming a plate specimen 11 inches long with the reduced section of 1 inch wide for a length of 2.2 inches. The results of the tests on the two bands is shown on page following:



119-1

119-2

TENSILE TESTS.

Marks.	Width (inches).	Thickness (inches.)	Sectional area (square inches).	Tensile strength.		Elongation in 2 inches.	
				Load (pounds).	Stress (pounds per square inch).	Inches.	Per cent.
Regular band	1.001	0.355	0.355	13,300	37,460	0.38	19
Manufacturer's band	1.000	.355	.355	11,200	31,540	.94	47

DIMENSIONS AT FRACTURE.

Marks.	Elongation in inch sections.		Width (inches).	Thickness (inches).	Sectional area (square inches).	Contraction of area (per cent).	Appearance of fracture.
	Inches.	Inches.					
Regular band	0.10	[1] 0.28	0.840	0.250	0.210	40.8	Light salmon, seamy.
Manufacturer's band.	.38	[1] .56	.710	.180	.128	63.9	Dark salmon.

[1] Inch section in which fracture occurred.

BRINELL HARDNESS TESTS.

[Brinell hardness tests were taken at three places on the bands.

Marks.	At inside.	At outside.	At edge.
Regular band	80	80	80
Manufacturer's band	48	45	40

In connection with these tests it is to be noted that although the tensile strength of the manufacturer's band is inferior to that of the band cut from seamless tubing, the hardness is decidedly less.

Micrograph No. 3747, at 50 diameters, shows the structure of the band taken from the seamless tubing. Micrograph No. 3748, at 50 diameters, shows the structure of the manufacturer's band.

It is very evident from these micrographs, as well as from the results of the tensile and hardness tests, that the seamless tubing band has received decidedly more cold work after the last annealing operation than the band made by the manufacturer, and consequently the tensile strength and Brinell hardness are both greater.

EXAMINATION OF AIR-HAMMER VALVE BROKEN IN FOUNDRY.

OBJECT.

The object of this investigation was to determine the character of the metal and the heat treatment given to the part in question.

CONCLUSIONS.

The chemical composition of the air-hammer valve, in so far as it could be determined, gave no indication as to why this piece should have failed.

Micro-examination showed that the part was casehardened, the case being in a good structural condition, but the core which should function as a support to the case was decidedly banded and did not show evidences of being properly treated.

That this structure may result in brittleness in a direction at right angles to the bands is supported by the facts observed upon examination of the broken mortar truck brake shaft reported in "Tests of Metals, 1915."

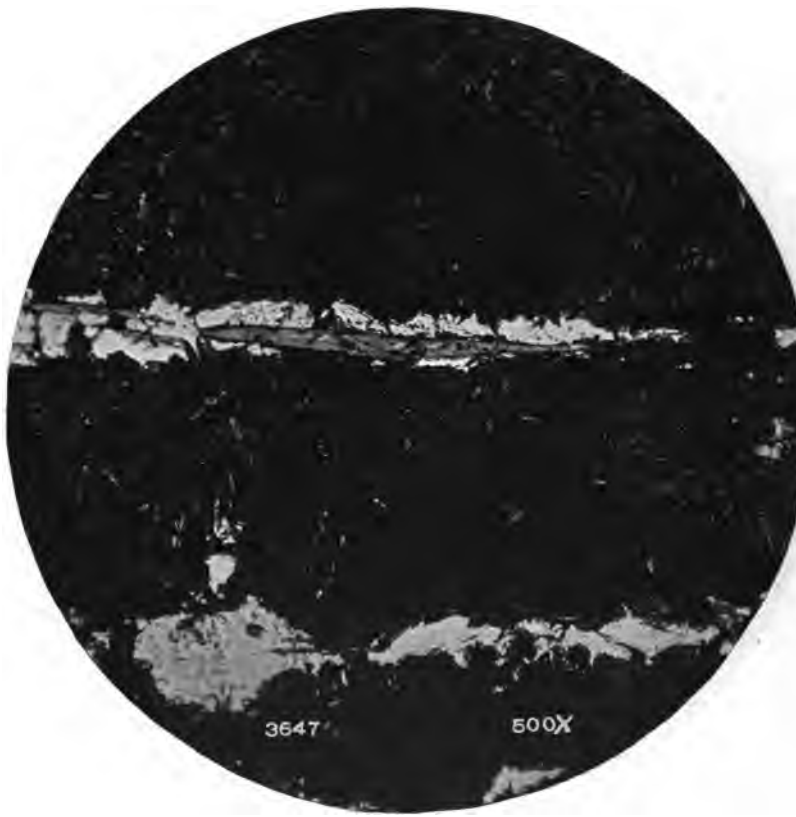
A longitudinal section of the valve guide showed that its working surfaces were casehardened. This is clearly shown in micrograph No. 3646. No defects can be pointed out in the case as its carbon content did not exceed 0. 85 per cent and showed neither free cementite or free ferrite, except locally. The piece had been so treated that the case was almost entirely troostitic, showing some traces of martensitic structure.

The core, however, was in a very bad condition, which is evident at a glance. The banding of ferrite and pearlite was most pronounced. It is, of course, questionable whether this condition would cause failure, but as it is an undesirable structure and one which can be partially obviated, as will be shown later, proper steps should be taken by the manufacturer to prevent the use of parts so apparently inferior.

This structure shows also that the double-quenching operation which should be given casehardened articles, was not given this piece, or else improperly carried out. This double quenching referred to consists in a quench from a relatively high temperature to refine the core, followed by a quench from a lower temperature to refine the case made coarse by the treatment for the core.

The occasional bands of ferrite present in the case, one of which is apparent in micrograph No. 3646, were very interesting in their occurrence. Micrograph No. 3647, 500 X, taken on one of these streaks shows ferrite crystallized out around slag streaks which are elongated, due to forging. This micrograph also shows the structure of the case to be troostitic, associated with a slight amount of martensitic structure.

120-1



120-2

121-1

121–2

123-1

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121-4

The specimen was then repolished and etched with Stead's reagent. Micrograph No. 3649, at 500 X, was taken after this etching and shows the structure of the core. This etching gives no additional information.

A simple treatment was next tried, which consisted in heating the specimen to 1,000° C. for one hour, followed by furnace cooling. Micrograph No. 3650 at 50 diameters, shows the resulting structure of the core. The banding has not been removed, and if any change is present, it is more pronounced than before. (See micrograph No. 3646, p. 120; micrograph No. 3650, p. 121.)

This behavior would at once indicate the segregation of some of the alloying constituents. Chemical analysis was carried as far as possible, but due to the small specimen available, nickel and phosphorus only were determined. Nickel was absent and the phosphorus was 0.05 per cent.

To obtain some idea as to what structure would be developed by quenching and drawing the core, a small specimen was heated to 1,000° C. and quenched in water.

Micrograph No. 3651, at 500 diameters, shows the resulting structure. This structure is typical of a low carbon steel after quenching. All traces of banding as far as could be determined with either nitric acid or Stead's reagent were absent.

The quenched specimen was then drawn one hour at 600° C. The structure resulting is shown on micrograph No. 3652 at 50 X. Banding is again apparent. This disappearance on quenching of the banded structure and its reappearance on drawing is characteristic of ferrite bands formed in steels in which, according to Stead, the phosphorus is segregated.

COMPRESSIVE TESTS OF STEEL BALLS.

OBJECT.

The object of this investigation was to determine if any of the steel balls on hand in the storehouse were defective. Complaint was made to one of the manufacturers that material furnished by them was not up to the requirements for steel balls. This complaint was made, as difficulty has been experienced in the machine shop, due to the failure of steel balls.

CONCLUSIONS.

The fracture of the ball was indicative of its crushing strength. Defective balls were found in the five-sixteenths inch and three-eighths inch diameter stock. The ultimate strength of the three-eighths inch diameter balls purchased from manufacturer No. 3, was less than that of the five-sixteenths inch balls purchased from manufacturer No. 2.

The curve on page 123 shows the relation between the ultimate strength and the diameter of the various balls tested.

EXPERIMENTAL.

The sizes of balls in stock were three-sixteenths, five-sixteenths, three-eighths, one-half, five-eighths, three-fourths and 1 inch diameter. From three to five balls were selected at random from each size for purposes of test.

The balls were crushed in the large Emery hydraulic testing machine between two nickel-chorme steel plates. These plates were hardened by heating to 1,050° C., followed by quenching in oil. The Brinell hardness of these plates was approximately 750.

In calculating the mean value of the ulitmate strength of any size ball, the value of the ultimate strength of the defective ball was not included in the mean. The results obtained are recorded in the table following, the ultimate strength of each ball tested being shown.

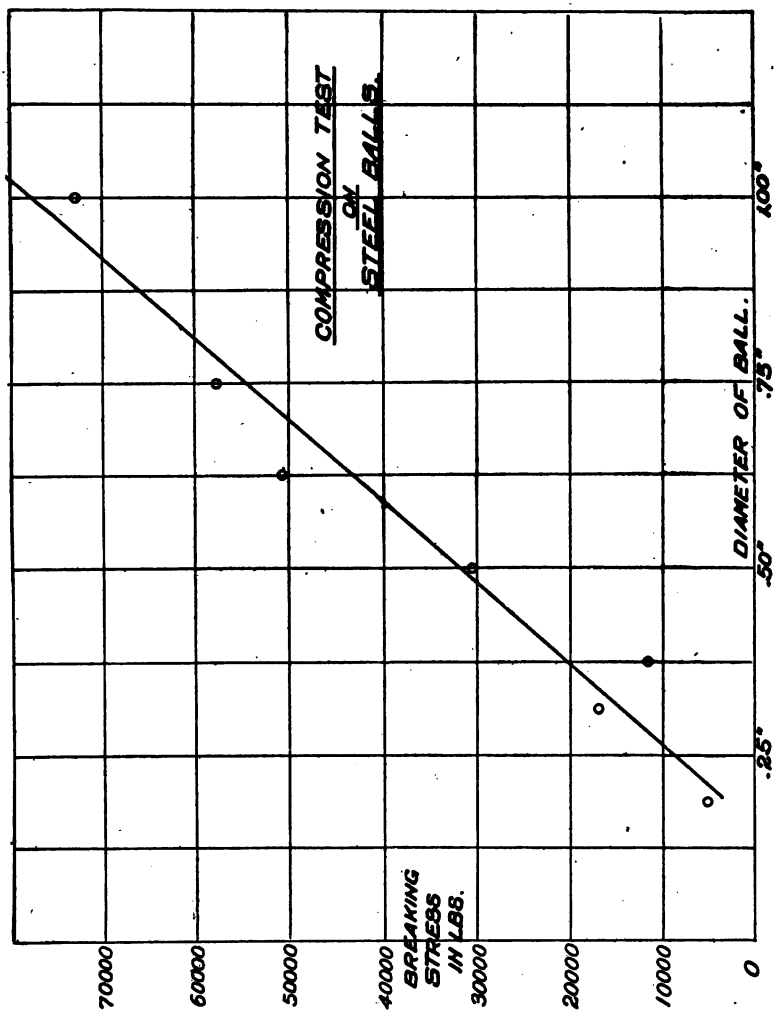
The photographs facing page 24 show the appearance of all the balls tested after fracture.

REMARKS ON PHOTOGRAPHS.

Ball No. 5 in the three-sixteenths inch size fractured at a load of approximately 1,000 pounds less than the mean. Upon examination of the fragments no trace of the formation of cones at the surfaces in contact with the steel plates could be found.

Ball No 1 in the five-sixteenths inch size, which broke at approximately 12,000 pounds less than the mean, split through a plane at right angles to the direction of the applied stress. Balls Nos. 2 and 3 of the five-sixteenths inch size developed two nearly perfect cones which are evident in the photograph.

The ultimate strength of the three-eighths inch balls was in all cases less than the ultimate strength of the five-sixteenths inch ball. The fracture showed a coarser structure and no cone was developed in ball No. 3 which broke at approximately 5,000 less than the mean value for this size.



All the balls tested in the one-half inch size showed a remnant of the cone, the cone, however, being crushed excepting in two or three instances. The fracture of ball No. 1 was very interesting as it shows one cone completely detached and one of the cones still attached to one of the larger fragments of the ball.

All of the five-eighths inch balls tested showed remnants of cones, the fracture being very fine.

Ball No. 2 of the three-fourth inch size gave an ultimate strength of approximately 8,000 pounds greater than the mean. It is to be

noted that the appearance of the fragments is different from either No. 1, 3, 4, or 5, the fracture showing a decidedly finer structure.

In testing ball No. 1 of the 1-inch size, one of the hardened steel plates was fractured at a load of 68,300 pounds. Upon release of this load the ball cracked, and after the insertion of a new plate the ball broke at 60,600 pounds. The fracture, however, was much finer than either ball No. 2 or No. 3.

From the balls examined it would seem that the greatest ultimate strength was obtained when the ball fractured by the formation of of two cones, the bases of which are formed at the surfaces in contact with the steel plates, or, in other words, parallel with the direction of the applied stress. The appearance of the steel ball after crushing gives a good indication of the quality of the steel ball.

COMPRESSIVE TESTS OF STEEL BALLS.

Number of balls tested.	Size of balls. diameter (inches).	Name of company submitting samples.
5	$\frac{1}{16}$	Manufacturer No. 1
3	$\frac{1}{8}$	Manufacturer No. 2.
3	$\frac{1}{4}$	Manufacturer No. 3.
5	$\frac{1}{2}$	Manufacturer No. 4.
5	$\frac{3}{4}$	Manufacturer No. 2.
5	$\frac{7}{8}$	Manufacturer No. 5.
3	1	Manufacturer No. 2.

Size of ball.	Ultimate strength (pounds).	Mean (pounds).	Remarks.
$\frac{1}{16}$ inch diameter	5,100 5,315 5,600 5,750 4,400	5,233	
$\frac{1}{8}$ inch diameter	[1] 4,800 18,600 15,200	16,900	
$\frac{1}{4}$ inch diameter	13,000 13,100 8,800	13,050	
$\frac{1}{2}$ inch diameter	29,300 31,900 26,300 30,000 34,800	30,460	
$\frac{3}{4}$ inch diameter	43,400 59,200 49,900 51,300 50,300	50,820	
$\frac{7}{8}$ inch diameter	56,700 65,700 52,300 56,600 58,600	57,980	
1 inch diameter	68,300 [1] 60,600 73,000 78,600	73,300	Fractured steel block. Fractured the ball.

[1] This figure not used in calculating the mean value.

3/16 inch.

5/16 inch.

3/8 inch.

1/2 inch.

3
1
3659
5/8 inch.

5
4
3660
5/8 inch.

3
2
3661
1
3/4 inch.

5
4
3662
3/4 inch.

3663
1 inch. No. 1

1 inch. No. 2

1 inch. No. 3

RESEARCH.

(Instituted for the purpose of improving Ordnance materials or the technique of their manufacture.)

INVESTIGATION OF GUN WIRE—REPORT OF PROGRESS.

STRENGTH OF BRAZED JOINTS AS AFFECTED BY TEMPERATURE.

In connection with the proposal to reline wire-wound guns it was thought necessary to investigate the behavior of the wire used in winding under the various temperatures which would be necessary in dropping out the old liner and inserting the new.

As the joints in the gun wire appear to be the probable weakest point, these were first investigated at different temperatures, using the apparatus described below, and on account of the apparent importance of the results obtained up to date, the results and certain conclusions based thereon are submitted herein so that any desirable action may be taken at once without waiting for completion of the entire report.

CONCLUSIONS.

Although the fracture occurs outside the joint in the case of electrically brazed specimens tested in tension at room temperature, it can not be said that the joint is "stronger than the wire," as the point of fracture is determined by the change in structure due to the heat necessary to brazing, and the breaking stress of the unaffected wire is at least 50 per cent greater than the strength shown by the brazed wire, even though, as noted above, it breaks in the clear wire outside of the joint.

The joint in the one-eighth inch wire separated along the scarf when tested at or above 211° C. The joint in the one-tenth inch wire separated along the scarf when tested at or above 234° C.

An inspection of the curves on pages 132 to 134 shows that the strength of the wire, including the joint, increases slightly with rising temperature. Beyond 175° C. the strength of the joint rapidly diminishes, and at 598° C. a load of 10,000 pounds per square inch was sufficient to cause the breaking of the joint.

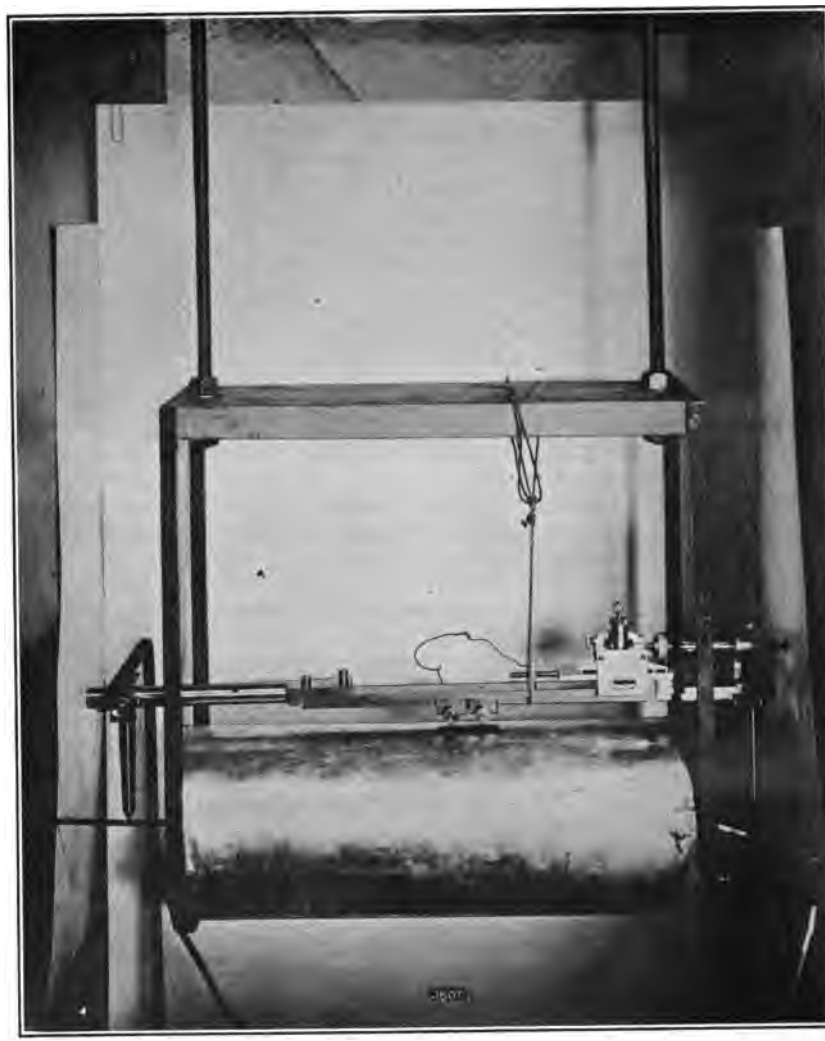
Microexamination of the structure at the brazed joint and at a short distance from this point shows that the brazing operation has greatly altered the structure in the vicinity of the joint. A very sharp line of demarcation exists between the original structure of the wire and the modified structure produced by the heat necessary in the brazing process.

MATERIAL USED IN THIS INVESTIGATION.

Nine sections of one-eighth inch square steel gun wire with electrically brazed joints approximately in the center and marked with firm name.

Eight sections of one-tenth inch square steel wire with electrically brazed joints in the center and marked with firm name.

In addition to the above, a number of short sections of each kind of wire with the electrically brazed joint in the center were available for testing purposes at room temperature.



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METHOD OF TEST.

Photograph No. 3507 shows the apparatus employed in testing the joints at the various temperatures. A small electrically heated tube furnace was constructed, the diameter of the heating tube being approximately one-half inch. The furnace was suspended in such a manner that after the wire had been passed through the furnace and clamped in the heads of the testing machine by the hydraulic grips it could then be adjusted in such a manner that the wire passed through the heating tube centrally. Using this arrangement there was no direct contact between the heating appliance and the wire being tested.

A gauge length of 15 inches was used in all cases. Special points were made for the extensometer, which enabled the instrument to be placed over the top of the furnace as shown in photograph No. 3507. Temperature measurements were made with a platinum couple, and it was found that when the furnace and wire to be tested were in place, a section approximately 9 inches long was uniformly heated. The entire temperature gradient occurred in a 1½-inch length at each end of the tube. The joint was always carefully located in the center of the furnace to insure its being heated to the temperatures recorded. The testing was carried out as follows:

The furnace was carefully brought to the desired temperature and held at this temperature for 30 minutes before the stresses were applied. The initial load was in all cases 5,000 pounds per square inch. The data table on page 129 gives the results of the tests on the one-eighth inch square steel wire when tested with the heating appliance in place. The results of the tests on the one-tenth inch square steel wire with the heating appliance in place are recorded on page 129. The tests on the short sections without the heating appliance in place, and for which no stress-strain diagrams were obtained on account of the shortness of the specimen, are recorded on page 130. The results obtained on the short section containing a riveted joint are also recorded on page 130.

DISCUSSION OF RESULTS.

The graph on page —, showing the relation between the strength of brazed joints in the one-eighth inch square wire and temperature at which they were tested, is very similar to the curve obtained on the one-tenth inch square wire. The breaking stresses of the one-tenth inch square wire were slightly higher at lower temperatures than the one-eighth inch square wire. The sudden break in the curve at approximately 175° C. in both cases is the striking feature of the experiment. It would seem possible to say that all breaks occurring to the left of this peak would not occur by a separation along the scarf, but rather by the "necking down" at the point where the original structure of the wire comes in contract with the structure produced by the heat generated in the brazing operation. All breaks to the right of the peak are caused by the separation along the scarf. There was no indication in any of the breaks along the scarf of fusion of brazing solder.

On page 131 are recorded the data obtained by heating a section of the one-tenth inch square wire under a constant load. The method employed was to heat gradually by allowing approximately 10-minute intervals to elapse at various temperatures. The joint

parted under a load of 10,000 pounds at 598° C. These same results are plotted on page 134. Discussion of the stress-strain diagram facing page 134 is of little interest.

Curve No. 8, facing page 134, of the one-eighth inch square wire and curve No. 6, facing page 134, of the one-tenth inch square wire, are very similar, and the specimens apparently have a different modulus from that prevailing for the other specimens tested. This is probably due to the fact that they both represent a specimen heated to over 400° C.

MICROEXAMINATION.

Micrograph No. 3508 shows the structure at the junction of the original structure of the wire with the structure as modified by the brazing operation. The junction of these two structures located an apparent point of weakness in the brazed joints when tested at temperatures below 175° C. Micrograph No. 3509, showing the structure at the brazed joint, reveals an entirely different type of structure from that present in the wire as received from the manufacturers. The structure incidental to cold work has been almost completely removed.

The following data prove very conclusively that the brazing operations do not give a joint which is stronger than the wire, although the fracture may occur outside of the joint. The sketch below will show the nature of the fracture in sections which did not separate along the scarf.

One section of the one-eighth inch wire, including the joint, broke as indicated in the above sketch at a stress of 127,000 pounds per square inch. The two ends of this wire were then pulled and broke under a stress of 200,000 pounds and 198,750 pounds, respectively. A section taken from the coil of one-eighth inch wire showed a breaking stress of 197,500 pounds, which is in very close agreement with the tests taken on the unaffected portion of the wire used in making the brazed joint sections.

A similar experiment was carried out on the one-tenth inch wire, and the results were in agreement with the above. The data below give the results in detail.

1/8" SQUARE WIRE.

Specimen.	Breaking stress when fracture occurs where the structure has been affected by brazing heat.	Breaking stress in unaffected wire.
No. 1	127,000	200,000
Specimen from coil		198,750 197,500

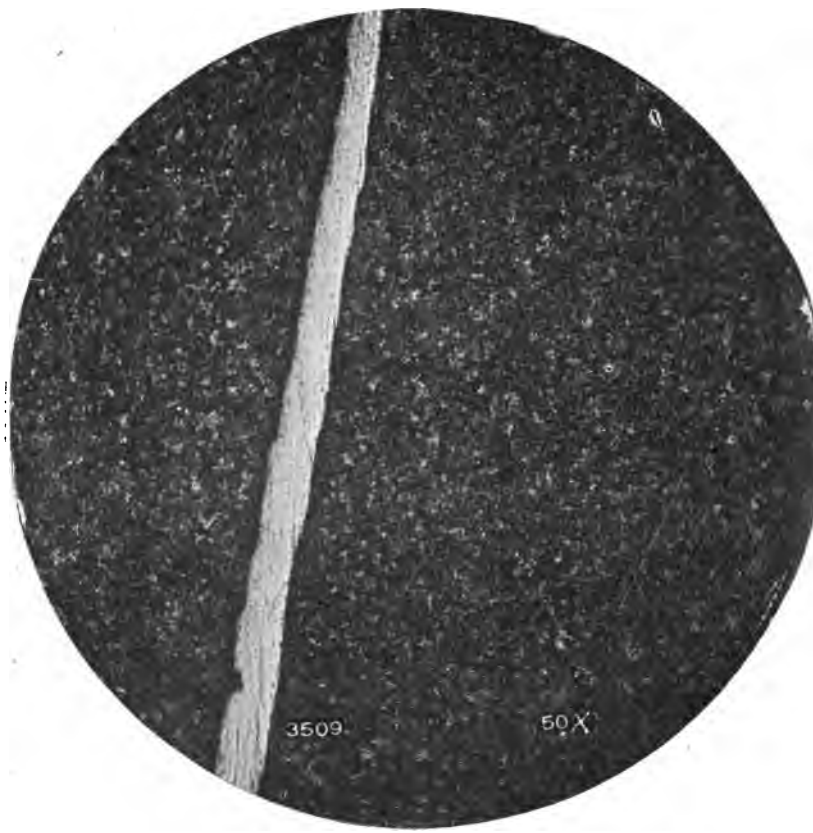
1/10" SQUARE WIRE.

No. 1	146,000	261,500
Specimens from coil		230,000 241,200 240 000

ORIGINAL STRUCTURE OF WIRE SHOWING EFFECTS OF COLD WORK.

Structure as modified by heat necessary to brazing. The junction of these two structures locates plane of weakness in wire.

128-1



Structure at brazed joint. Effect of cold working almost entirely removed. The structure from the junction shown in micrograph No. 3508 gradually becomes coarser, proceeding from the junction toward the joint.

TENSILE TESTS OF ONE-EIGHTH-INCH SQUARE STEEL WIRE, WITH BRAZED JOINT.

Taken in large Emery testing machine with heating appliance in place.

Gauge length, 15 inches.

Test No.	Size wire (inch).	Sectional area (square inch).	Temperature at which heated.	Tensile strength.		Position of fracture.
				Total (pounds).	Stress (pounds per square inch).	
			° C			
1.....	⅛	0.0160	.....	2,030	127,000	Fractured the wire at end of brazed joint.
2.....	⅛	0.0160	.....	1,780	111,000	Separated along the scarf joint.
3.....	⅛	0.0160	136	2,016	126,000	Fractured the wire at end of brazed joint.
4.....	⅛	0.0160	136	2,225	140,000	Do.
7.....	⅛	0.0160	211	2,016	126,000	Separated along the scarf joint.
9.....	⅛	0.0160	259	1,200	75,000	Do.
5.....	⅛	0.0160	294	1,235	77,000	Do.
6.....	⅛	0.0160	294	850	53,000	Do.
8.....	⅛	0.0160	406	672	42,000	Do.

TENSILE TESTS OF ONE-TENTH-INCH SQUARE STEEL WIRE, WITH BRAZED JOINT.

Taken in large Emery testing machine with heating appliance in place.

Gauge length, 15 inches.

Test No.	Size wire (inch).	Sectional area (square inch).	Temperature at which heated.	Tensile strength.		Position of fracture.
				Total (pounds).	Stress (pounds per square inch).	
			° C			
2.....	1/10	0.010	136	1,460	146,000	Fractured the wire at end of brazed joint.
3.....	1/10	0.010	186	1,560	156,000	Do
4.....	1/10	0.010	234	1,200	120,000	Separated along the scarf joint.
5.....	1/10	0.010	276	800	80,000	Do.
1.....	1/10	0.010	317	840	84,000	Do.
7.....	1/10	0.010	351	720	72,000	Do.
6.....	1/10	0.100	427	440	44,000	Do.

TENSILE TESTS OF SHORT PIECES OF ONE-EIGHTH-INCH SQUARE STEEL, WIRE WITH BRAZED JOINTS.

Length of samples over all 12 inches.
Length of scarf joints about seven-eighths inch.

No.	Tensile strength.		Manner of failure.
	Load (pounds).	Pounds per square inch.	
1	2,119	132,000	Fractured wire about $\frac{1}{16}$ inch from end of scarf.
2	2,037	128,000	Fractured wire about $\frac{1}{8}$ inch from end of scarf.
3	2,145	134,000	Separated along the scarf.
4	2,138	133,000	Fractured the wire at end of scarf.
5	2,100	131,000	Do.
6	2,205	138,000	Fractured the wire about $\frac{1}{8}$ inch from end of scarf.

RIVETED JOINT, LONG SCARF. ONE-EIGHTH INCH SQUARE.

1	1,400	87,500	Fractured across both scarfs at a rivet hole about half way along scarf.

TENSILE TESTS OF SHORT PIECES OF ONE-TENTH-INCH SQUARE STEEL WIRE.

Length of sample over all = 12 inches.

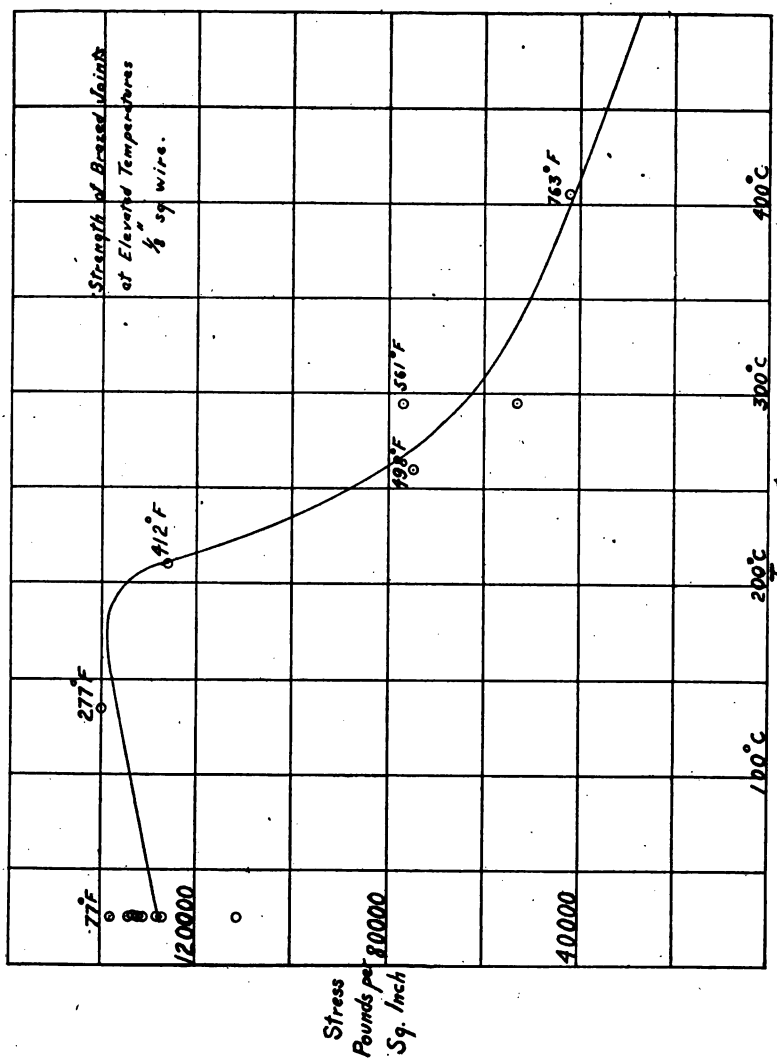
No.	Tensile strength.		Manner of failure.
	Load (pounds).	Pounds per square inch.	
1	1,425	142,500	Fractured the wire at end of scarf.
2	1,435	143,500	Separated along the scarf and fractured one scarf 0.60 inch from end of scarf.
3	1,421	142,100	Fractured wire at end of scarf.
4	1,412	141,200	Separated along the scarf and fractured 1 scarf $\frac{1}{8}$ inch from end of scarf.
5	1,528	152,800	Fractured one scarf $\frac{1}{16}$ inch from end of scarf.
6	1,400	140,000	Fractured wire $\frac{1}{8}$ inch from end of scarf.

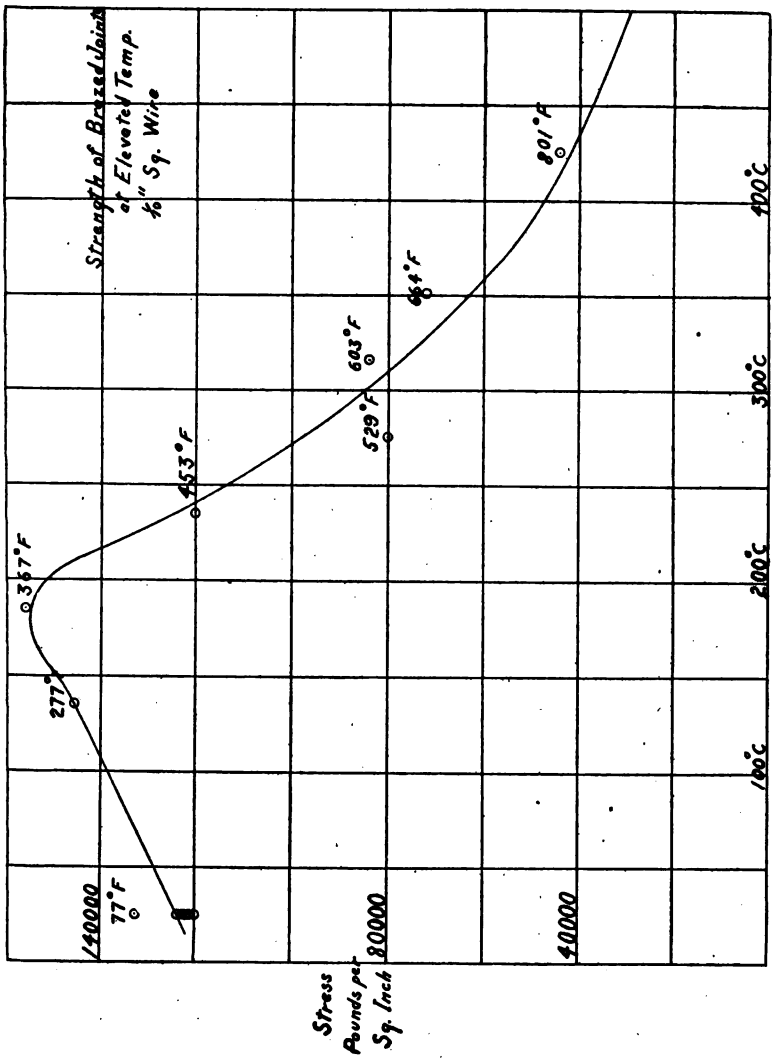
TENSILE TEST OF ONE-TENTH-INCH SQUARE STEEL WIRE WITH BRAZED JOINT.

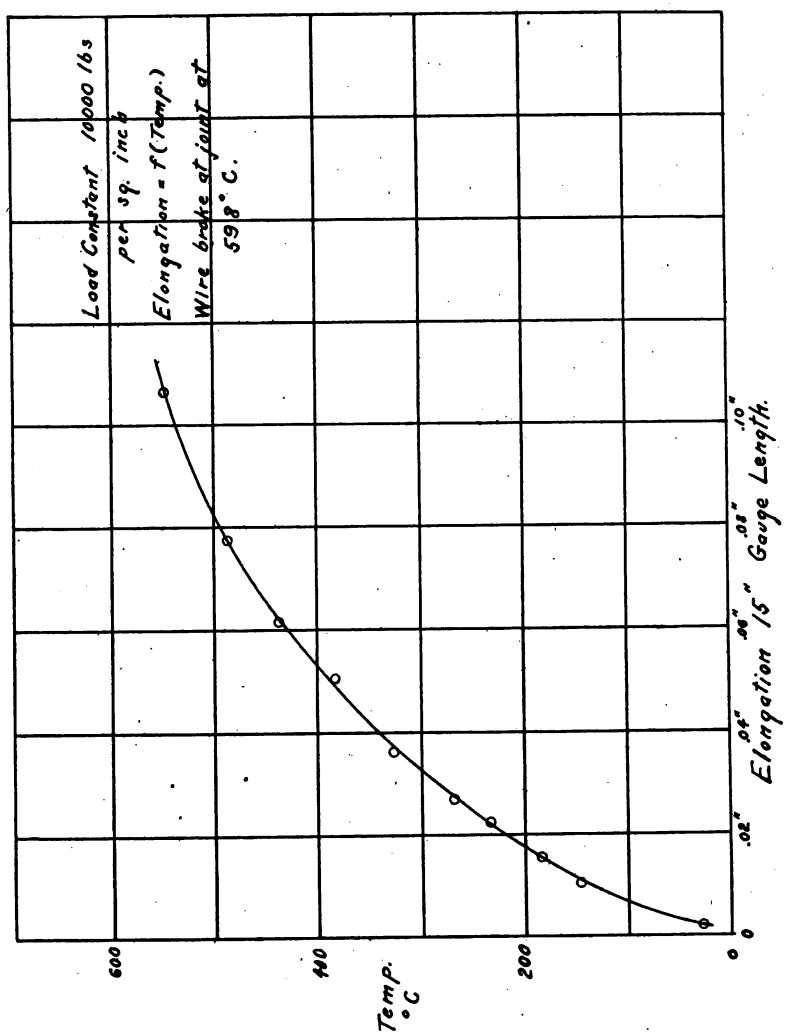
TEST NO. 7.

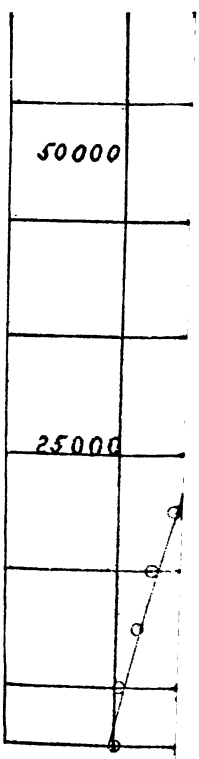
Constant load and temperature gradually increased.
Sectional area = 0.010 square inch.
Gauged length = 15 inches.

Applied loads (pounds per square inch).	Micrometer readings (elongation).	Heat degrees (°C.).	Time.	Remarks.
10,000	−.0015	28	1.35	Initial load.
10,000	+.0090	136	1.45	
10,000	.0099	136	1.55	
10,000	.0140	186	1.59	
10,000	.0150	186	2.10	
10,000	.0195	234	2.15	
10,000	.0220	234	.....	
10,000	.0255	271	2.25	
10,000	.0266	271	2.35	
10,000	.0330	328	2.40	
10,000	.0360	328	2.50	
10,000	.0440	384	2.55	
10,000	.0498	384	3.05	
10,000	.0575	438	3.15	
10,000	.0615	438	3.25	
10,000	.0705	488	3.30	
10,000	.0775	488	3.40	
10,000	.0955	548	3.47	
10,000	.1061	548	3.57	
10,000	.1315	598	4.05	About 1 minute after the readings were taken the joint separated along the scarf.


Strength of Brazed Joints
at Elevated Temperatures
⅛" sq wire.
77°F
277°F
412°F
498°F
561°F
763°F
120000
80000
40000
Stress
Pounds per
Sq. Inch
100°C
200°C
300°C
400°C
Temperature


Strength of Brazed Joints
at Elevated Temp.
⅜" Sq. Wire
Stress
Pounds per
Sq. Inch
140000
120000
100000
80000
60000
40000
71°F
367°F
277°
453°F
529°F
603°F
664°F
801°F
100°C
200°C
300°C
400°C


Load Constant 10000 lbs per sq. inch
Elongation = f(Temp.)
Wire broke at joint at 598° C.
600
400
200
0
Temp. °C
0
.02"
.04"
.06"
.08"
.10"
Elongation 15" Gauge Length.


50000
25000

INVESTIGATION OF EFFECTS ON GUN WIRE OF SUCH HEATING AS IT WOULD RECEIVE DURING ORIGINAL INSERTION OF TUBE OR SUBSEQUENT RELINING.

In order to obtain the necessary data as to the effect of the relining temperatures upon the wire, the following program of tests was arranged.

PROGRAM OF TESTS.

1. PHYSICAL TESTS.

(*a*) Physical tests on one-eighth inch and one-tenth inch wire as taken from the reel.
(*b*) Physical tests on one-eighth inch wire annealed at 450° C. in coil for one hour.
(*c*) Physical tests on one-eighth inch wire annealed at 600° C. in coil for one hour.
(*d*) Physical tests on one-eighth inch wire heat treated in various ways in a furnace to be described later.

2. MICROSCOPICAL INVESTIGATION AND CRITICAL POINTS.

(*a*) Microscopical examination of specimens from a, b, c, and d.
(*b*) Cooling curves on one-eighth inch square gun wire.

3. PERMANENT SET TESTS.

(*a*) Tension on wire 60,000 pounds, maximum temperature of heating variable.
(*b*) Tension on wire 60,000 pounds, rate of heating variable.
(*c*) Tension on wire 60,000 pounds, held at maximum temperature six hours, maximum temperature variable.
(*d*) Tension on wire 47,500 pounds, held six hours at maximum temperature, maximum temperature variable.
(*e*) Tension on wire 37,500 pounds, held six hours at maximum temperature, maximum temperature variable.
(*f*) Tension on wire 60,000 pounds, held six hours at maximum temperature. Variables of series were physical properties of wire occasioned by previous heat treatment and maximum temperature of heating.
(*g*) Tension on wire 47,500 pounds, held six hours at maximum temperature. Variables of series were physical properties of wire occasioned by previous heat treatment and maximum temperature of heating.
(*h*) Tension on wire 37,500 pounds, held six hours at maximum temperature. Variables of series were physical properties of wire occasioned by previous heat treatment and maximum temperature of heating.

This report includes the following:

1. Conclusions in brief, with suggestions.
2. Physical tests on gun wire, treated and untreated.
3. Tests on gun wire heated to different temperatures under constant load to determine resultant permanent sets.
4. Microscopical examination of material both in treated and untreated states.
5. Calculations showing fiber stresses in gun wire at different stages in the fabrication of a wire-wound gun.
6. Record of the data obtained in the permanent set experiments.

CONCLUSIONS.

The wire used in present wire-wound gun construction is cold drawn after the last annealing operation during its manufacture. For that reason it is in a condition very susceptible to heat treatments applied below the critical range. Such an annealing will cause a decrease in the tensile strength accompanied by the appearance of a true elastic limit.

Concerning the question of "slow creep" in this wire under load, the experiments carried out in connection with this investigation indicate that with loads not exceeding 55,000 pounds per square inch the initial elongation is but slightly exceeded by continuing the wire under the tension at which the initial elongation was determined, and, furthermore, the additional extension developed occurred entirely in the first few minutes of the time during which the wire was continued in tension. For additional conclusions concerning this point see page 140.

When the wire was heated under tension permanent sets were developed which varied with the load and temperature of heating. The following table shows the influence of tension and maximum temperature of heating on the amount of permanent set. All the wires were heated quickly to the maximum temperature and held six hours.

Temperature (° C.).	Per cent set of original gauge length.		
	37,500 pounds.	47,500 pounds.	60,000 pounds.
228 222 230	0.033	0.058	0.075
271 271 271	.083	.108	.142
300 300 302	125	.142	.192
351 350 350	.208	.258	.333
373 373 373	.275	.317	.542

The per cent elongation produced by the load in each case was approximately as follows.

	Per cent.
60,000 pounds	0.220
47,500 pounds	.170
37,500 pounds	.130

A number of similar permanent set experiments were conducted on wire so heat treated that a true elastic limit was developed. The permanent sets resulting in such wire heated under tension are so decidedly less than those occurring in cold-worked material that it seems apparent such a wire must be adopted for gun construction if any heating operations are to be employed either in assembling or relining.

In the portion of this report under calculations, pages 175 to 179, inclusive, the formula $y+\frac{d}{2r}M$ is developed, where y = winding tension, d = thickness of wire, r = radius of tube or coil, and M = modulus of wire, which is considered constant at all stresses. This formula enables the computation of the fiber stress in the wire at any plane.

It is shown further that in the 10-inch rifle, wire wound, 30 tons, designed by Gen. Crozier (Notes on Construction of Ordnance, No. 87), that the tension on the extreme outside fibers of the first layer of wire is 185,600 pounds per square inch at the conclusion of the winding of the first layer if 0.1 inch square wire is used.

If wire in a ribbon form having a section 0.03 inch by 0.33 inch was used on this gun in the same location and under the same winding tension, the fiber stress on the extreme fibers of the first layer would be 80,000 pounds per square inch, giving a reduction in maximum stress at rest of 105,600 pounds. These calculations, as previously stated, imply a constant value of M, or, in other words, a perfectly elastic wire under all conditions of stress. This condition can not be realized when the stresses are very great, as the elastic limit will be exceeded.

From consideration of the term $\frac{d}{2r}M$ it is evident that streeses due to bending can be reduced by decreasing d, or, in other words, using a thin wire. From the manufacturer's viewpoint the fabrication of the ribbon-form wire would involve but little, if any, increase in cost over the present form.

It is assumed that the wire envelope of a gun should be perfectly elastic. To fulfill the above condition it is necessary that the wire should be an elastic body before being wound on the gun, which is not the case at present, and secondly, that the algebraic sum of all stresses to which the wire is subjected during and after winding on the gun must not exceed the elastic limit of the material comprising the wire.

Either square or flat wire can be secured which is an elastic body and to insure this, present specifications should be so modified that the last operation in the manufacture of the material must be an oil quench from above the critical range followed by tempering at a temperature well above that necessary for assembling or relining a gun. Such wire is known as a hardened and tempered wire and is used for springs, razor blades, etc.

It is not apparent how any of the advantages inherent to hardened and tempered wire will be realized if the present practice of using a large square wire is continued. This follows from the fact that with a thick wire the stresses resulting from bending the wire around the tube will be very great in the extreme fibers, causing the algebraic sum of all the stresses to exceed the elastic limit. Any

annealing operation incidental to assembling or relining will therefore change the physical properties of the overstrained portion of the wire and very probably produce permanent sets.

The proper course of action would seem to be a change from square to ribbon form wire and the specifying of hardened and tempered material which could be treated so as to give an elastic limit of 100,000 to 120,000 pounds per square inch.

It would also seem that the use of a hardened and tempered ribbon wire would assist in the solution of the joint problem. An electrically welded joint could be made and subsequently heat-treated, using the same temperatures for hardening and tempering as were applied to the wire in its manufacture. As a last resort recourse could be had to the riveted joint such as used in English construction, the rivet holes in the flat wire being much less effective in reducing cross section than in the square wire.

RESULTS OF PHYSICAL TESTS.

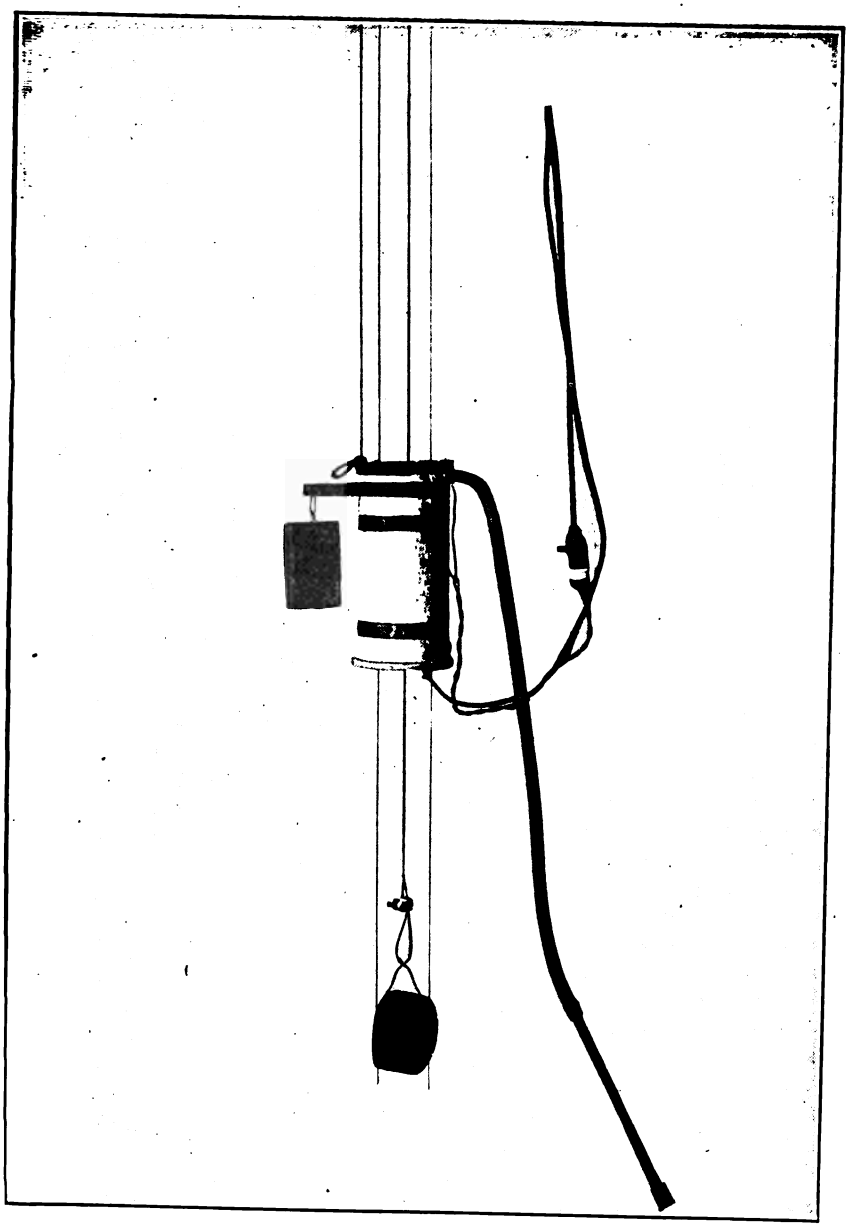
As it was desirable, as will be shown later, to obtain a truly elastic wire for the set tests, some means was necessary to heat-treat the wire so that in the treated condition it would be straight and not in the form of a coil. To enable this to be done, a furnace was constructed as shown in photograph No. 3684, on the opposite page.

This apparatus consisted of a nichrome-wound electric furnace moving vertically between wire guides. A rope attached to the furnace and passing through a pulley directed overhead was brought out to a small windlass. This enabled the furnace to be moved up or down by any desired amount. A base metal couple was secured in the center of the heating tube and the lead wires carried to a portable potentiometer.

The heat treatment of a wire was carried out as follows: The furnace was raised to the top of the guides, the wire to be treated being fastened to a plate directly over the center of the tube, and the desired weight to the bottom of the wire. The furnace was then brought to the desired temperature and fed down along the wire at any desired rate. For example suppose the recorded treatment is $800° - 2'' - 30 - 2{,}000$. This means that the furnace was brought to 800° C., fed downward 2 inches every 30 seconds, the weight on the wire being 2,000 pounds per square inch.

In some cases the wire was cooled by means of an air blast directed up or down as it emerged from the furnace, whereas in others it was allowed to cool freely without the assistance of the blast. In the data tables "cooled in air" signifies cooling without the assistance of an air blast.

The results of the physical tests and the strees-strain diagrams for each test are recorded herewith. The data from which the stress-strain diagrams are plotted is on file in the testing laboratory.



PHYSICAL TESTS ON ONE-EIGHTH INCH SQUARE GUN WIRE.

No. of test.	Treatment (all °C.).	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).
1	800°+25°, heated by blast lamp, 750 pounds on wire	65,000	108,750
2	600°—1 hour in coil, furnace cooled	45,000	120,000
3	600°—1 hour in coil, furnace cooled	45,000	121,250
4	450°—1 hour in coil, furnace cooled	40,000	162,800
5	450°—1 hour in coil, furnace cooled	35,000	158,750
6	800°—2—30, air cooled, 2,000 pounds on wire	75,000	130,000
7	800°—2—30, air cooled, 2,000 pounds on wire	74,000	111,250
8	800°—2—30, air cooled, 1,200 pounds on wire	65,000	115,600
9	800°—2—30, air cooled, 1,200 pounds on wire	73,000	112,000
10	800°—½—10, air blast down, 1,200 pounds on wire	80,000	97,500
11	800°—½—10, air blast down, 1,200 pounds on wire	80,000	124,400
12	800°—½—10, air blast up, 1,200 pounds on wire	79,000	121,125
13	800°—½—10, air blast up, 1,200 pounds on wire	79,000	133,125
14	800°—½—10, air cooled, 2,000 pounds on wire	75,000	120,625
15	800°—½—10, air cooled, 2,000 pounds on wire	75,000	130,925
16	1,000°—½—10, air blast up, 1,200 pounds on wire	70,000	140,300
17	1,000°—½—10, air blast up, 1,200 pounds on wire	70,000	143,600
18	800°—½—10, air blast up, 2,000 pounds on wire	80,000	116,000
19	800°—½—10, air blast up, 2,000 pounds on wire	75,000	127,750
20	1,000°—½—10, broke, air blast up, 2,000 pounds on wire	75,000	127,625
21	1,000°—½—10, air blast up, 2,000 pounds on wire	75,000	142,360
22	1,000°—½—10, air blast up, 2,000 pounds on wire	75,000	140,500
23	800°—2—30, air blast up, 2,000 pounds on wire	70,000	102,000
24	800°—2—30, air blast up, 2,000 pounds on wire	79,000	135,625
25	800°—6 inches up—3 down, water, 2,000 pounds on wire	35,000	35,000
26	800° in coil, air cooled	10,000	99,000
27	Wire from coil	(1)	193,500
28	Wire from coil	(1)	193,750

[1] Permanent sets from 0.0007 to 0.001 at 55,000 pounds elastic limit below this stress.

An inspection of the results from tests 2 and 3, 4 and 5, and 27 and 28, are of particular interest. Five turns were taken from the coil and annealed in this form for one hour at 600° C. or 1,112° F. The mean value of the elastic limit was 45,000 pounds and the tensile strength 120,500 pounds.

The value of the elastic limit and tensile strength of the specimens taken from the coil annealed at 450° C. were 37,500 and 160,000 pounds per square inch, respectively.

For specimens taken directly from the coil as received and tested, the tensile strength was approximately 193,000 pounds, whereas no elastic limit could be determined.

These results show conclusively that annealing applied below the critical range of the material causes a decrease in the tensile strength accompanied by the appearance of an elastic limit, annealing at 600° C. having lowered the tensile strength approximately 70,000 pounds, whereas the elastic limit was raised from 0, or at least very low value, to 45,000 pounds.

Specimens 6 to 25 inclusive represent wire which had been treated in the furnace previously described. Great variation existed in the elastic limit and tensile strength. The one-half inch feed every 10 seconds gave more consistent results than the 2-inch feed every 30 seconds. The most important point to be borne in mind, however, is the fact that the heat-treated wires were carried to the "set experiments" in a truly elastic condition with the wire straight.

Specimen No. 26 is of particular interest and its stress-strain diagram, page 146, should be noted. The wire from which the specimen was taken was heated in a coil approximately 2½-inch

diameter to 800° C. and cooled in air. Specimens 27 and 28 were tested from the coil as received. The test was conducted as follows: The load was first increased from 10,000 pounds to 55,000 pounds, held at this load for 30 minutes, the load then reduced to 10,000 pounds, subsequently increased again to 55,000 pounds, reduced again to 10,000 pounds and then increased to the breaking stress. The following data table summarizes the results obtained:

SPECIMEN 27.

Time.	Load.	Elongation.	Set.
.....	10,000	0.0003	.....
3.27	55,000	.0256	.....
3.32	55,000	.0263	.....
3.37	55,000	.0265	.....
3.47	55,000	.0266	.....
3.52	55,000	.0265	.....
3.57	55,000	.0265	.....
3.59	10,000	.0010	0.0007
4.04	10,000	.0007	.....
4.09	10,000	.0010	.....
4.11	55,000	.0266	.....
4.15	55,000	.0266	.....
4.17	10,000	.0011	.0008
.....	55,000	.0267	.....
.....	193,500	(1)	.....

SPECIMEN 28.

.....	10,000	0.0021	.....
1.19	55,000	.0288	.....
1.24	55,000	.0289	.....
1.29	55,000	.0290	.....
1.34	55,000	.0290	.....
1.39	55,000	.0291	.....
1.44	55,000	.0291	.....
1.49	55,000	.0291	.....
1.52	10,000	.0037	0.0010
1.59	10,000	.0032	.....
2.03	55,000	.0292	.....
2.08	55,000	.0291	.....
2.13	55,000	.0292	.....
2.15	10,000	.0032	.0011
2.20	10,000	.0032	.....
.....	193,750	(1)	.....

[1] Breaking stress.

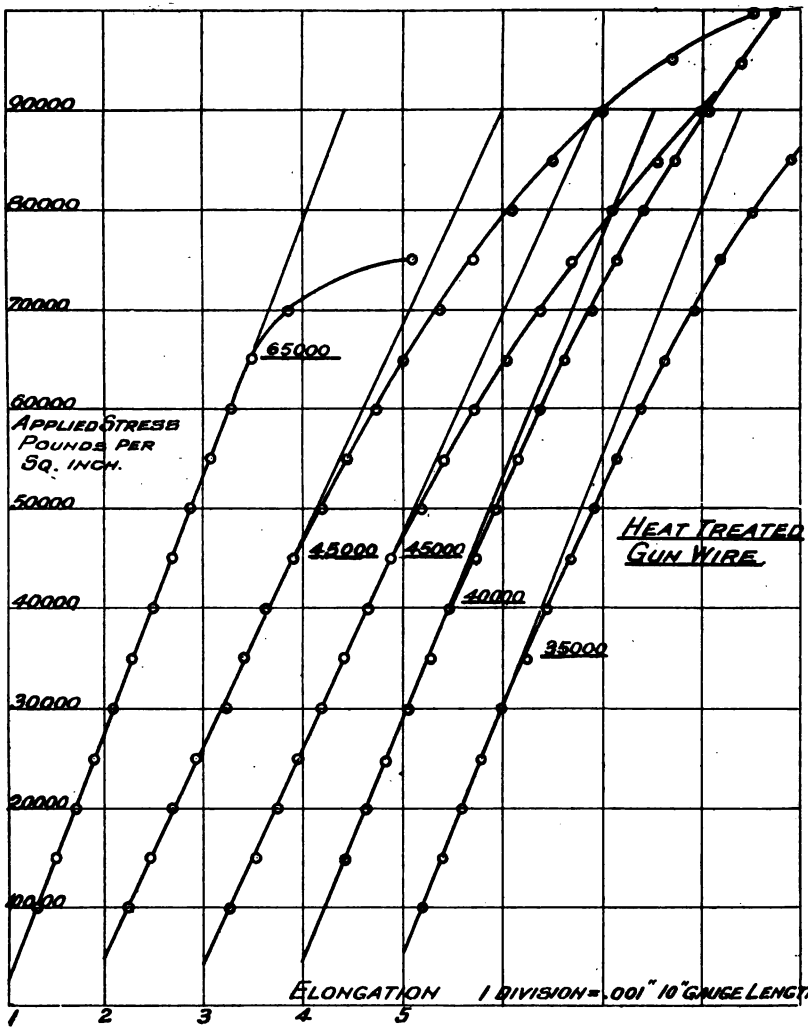
These results show that the elongation at 55,000 pounds per square inch will vary depending upon the time the specimen is held at that load, but in all cases the elongations due to holding under constant stress are small compared to the total elongation produced by the given load.

In other words, the momentary elongation in specimen 27 was 0.0256 inch at 55,000 pounds. The elongation after 30 minutes was 0.0265 inch, or an increase of 3.5 per cent, and the increase was observed in the first 10 minutes, the last 20 minutes giving no additional elongation.

The momentary elongation in specimen No. 28 was 0.0288 inch at 55,000 pounds, and after 20 minutes at this load was 0.0291 inch, an increase of 0.0003 inch, or approximately 1 per cent.

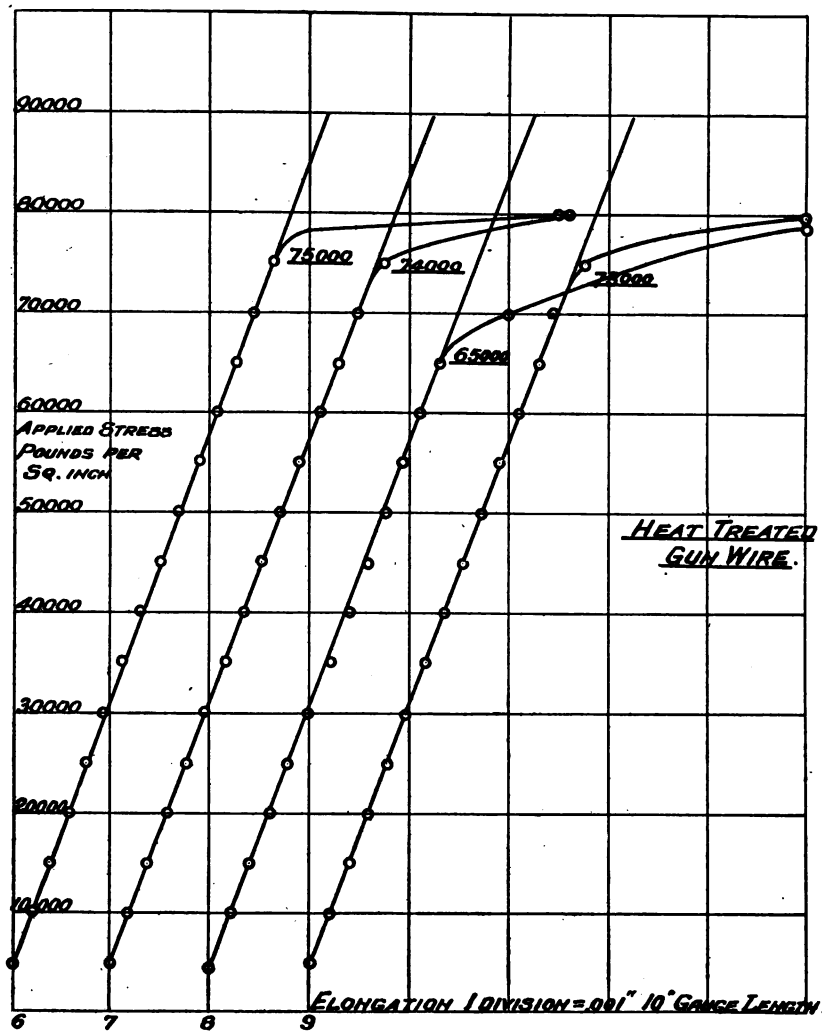
The second application of 55,000 pounds produced a greater extension than the first application of this same stress, but the data obtained indicates that the momentary elongation was the same as the elongation present after this load had been applied several minutes.

The elastic limit of specimen No. 26, page 146, as shown by the stress-strain diagram, was certainly not over 10,000 pounds. As a steel of the composition shown by the wire used should assume at least an elastic limit of 80,000 pounds by this treatment in a section one-eighth inch by one-eighth inch, the only explanation is that the wire or a considerable portion of it at least was stressed beyond its elastic limit by the operation of straightening in the testing machine.

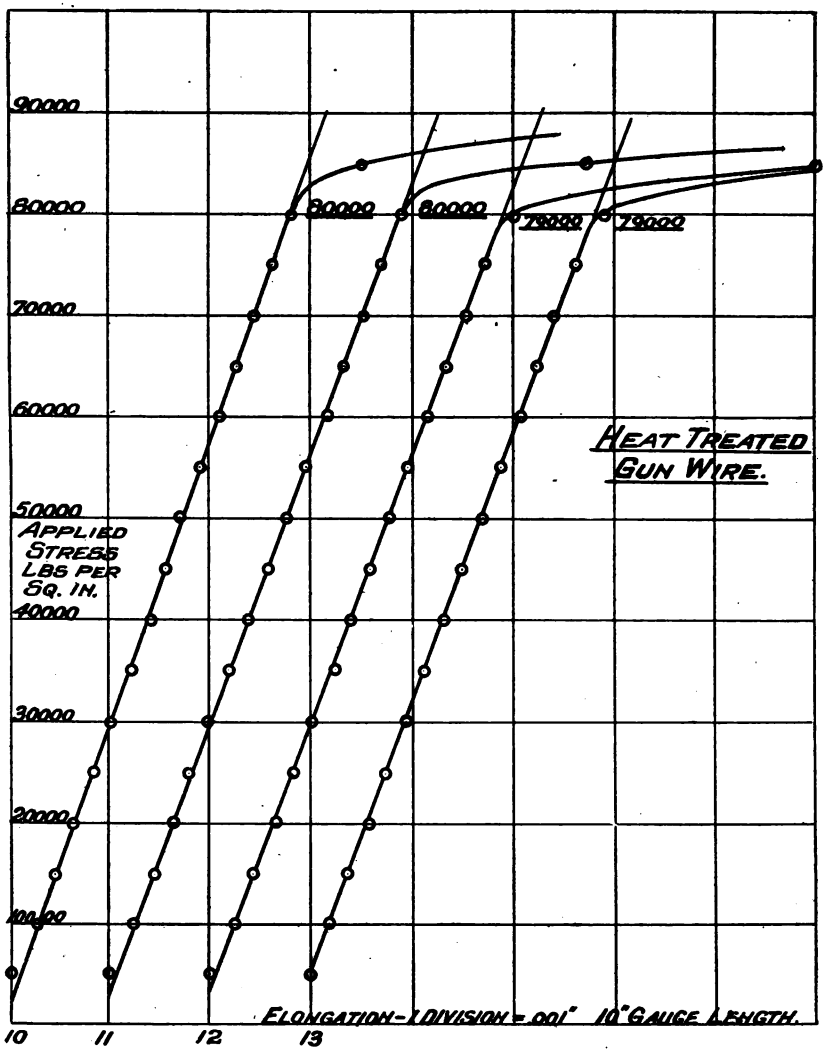


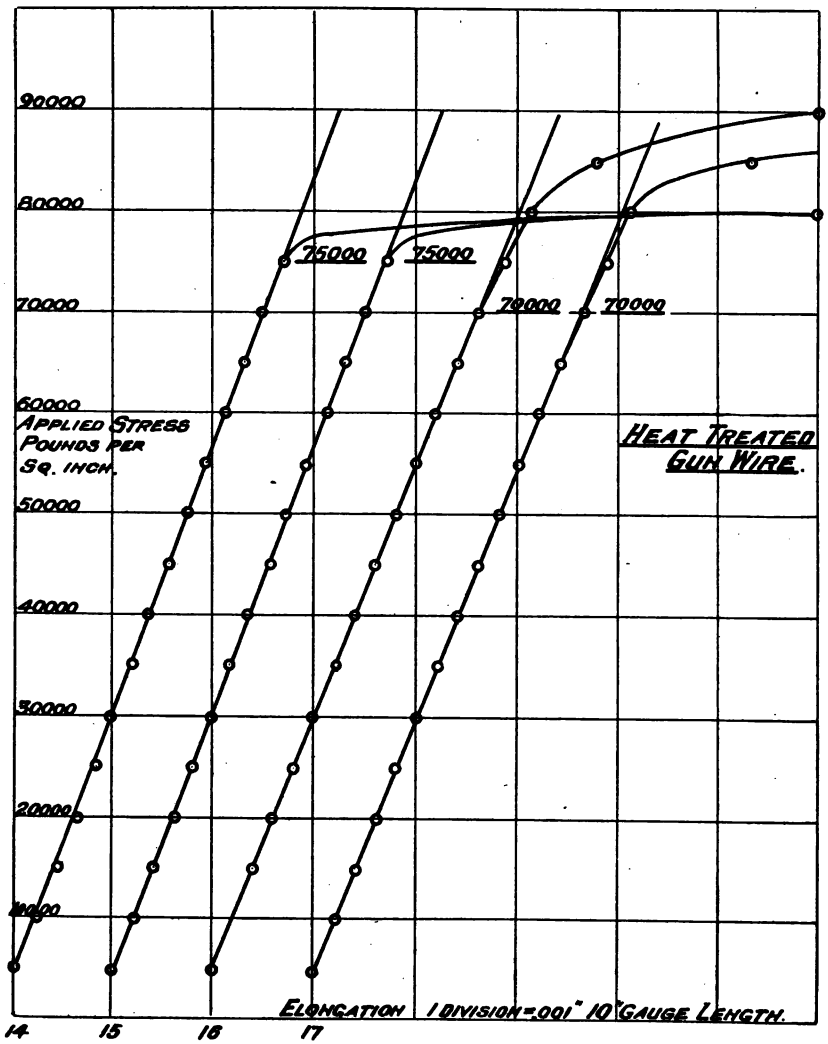
This might at once suggest the possibility in the testing of a specimen of gun wire as it comes from the reel that the reason no elastic limit is found is due to a cause similar to the above. To raise this point is entirely reasonable, but there is other evidence which indicates that this is not the case. It is known that straightening the wire carefully before testing does not give sufficiently

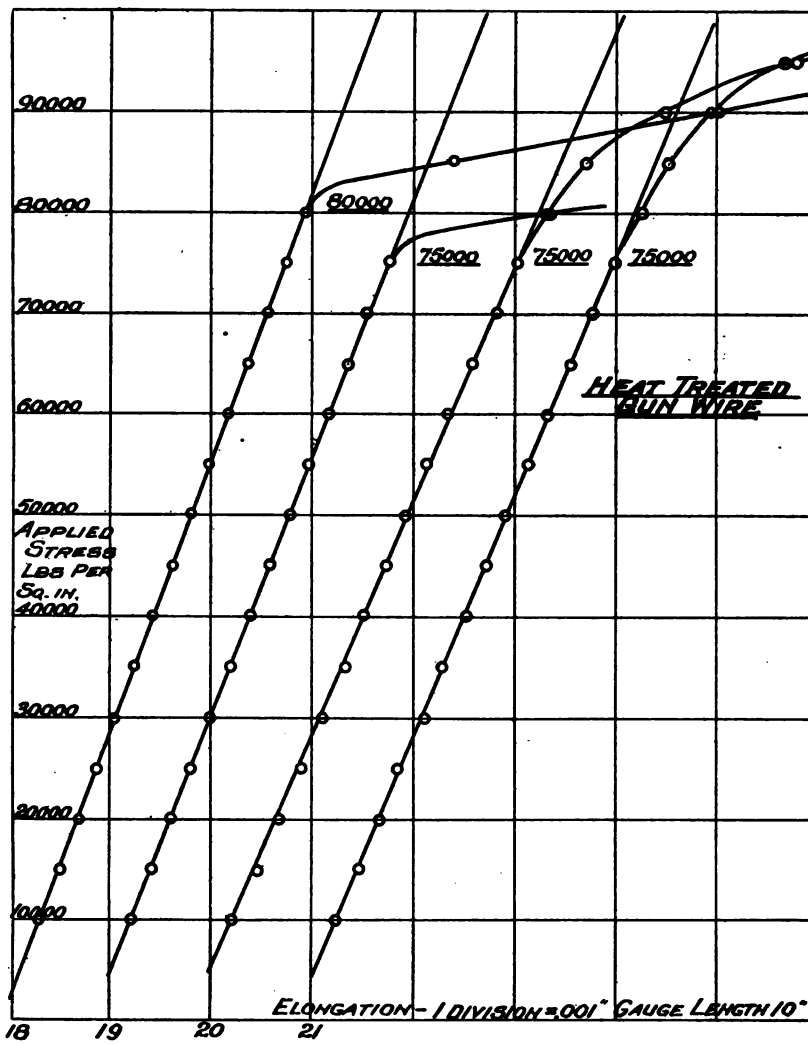
great differences in physical properties to warrant the conclusion that the wire as received on the reel is an elastic body. Furthermore, permanent sets are noted in this material under very low stresses, and also the microstructure is such as would indicate that the anneal given this wire subsequent to its last drawing must have been carried out at a very low temperature.

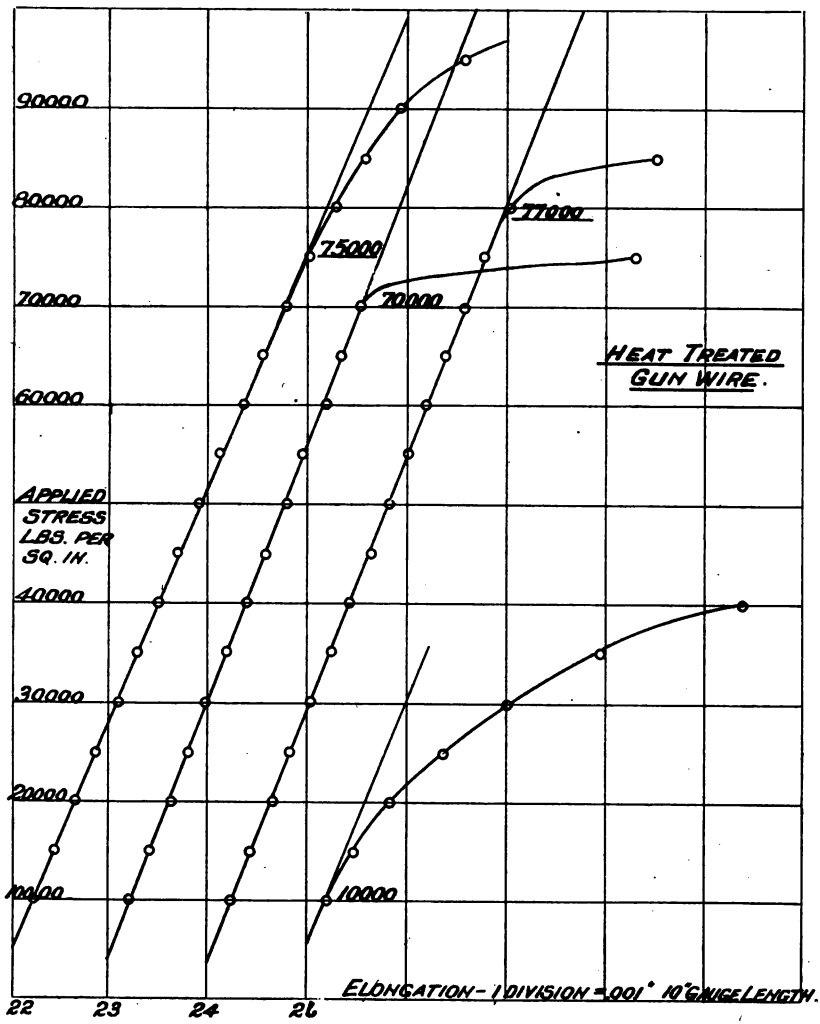


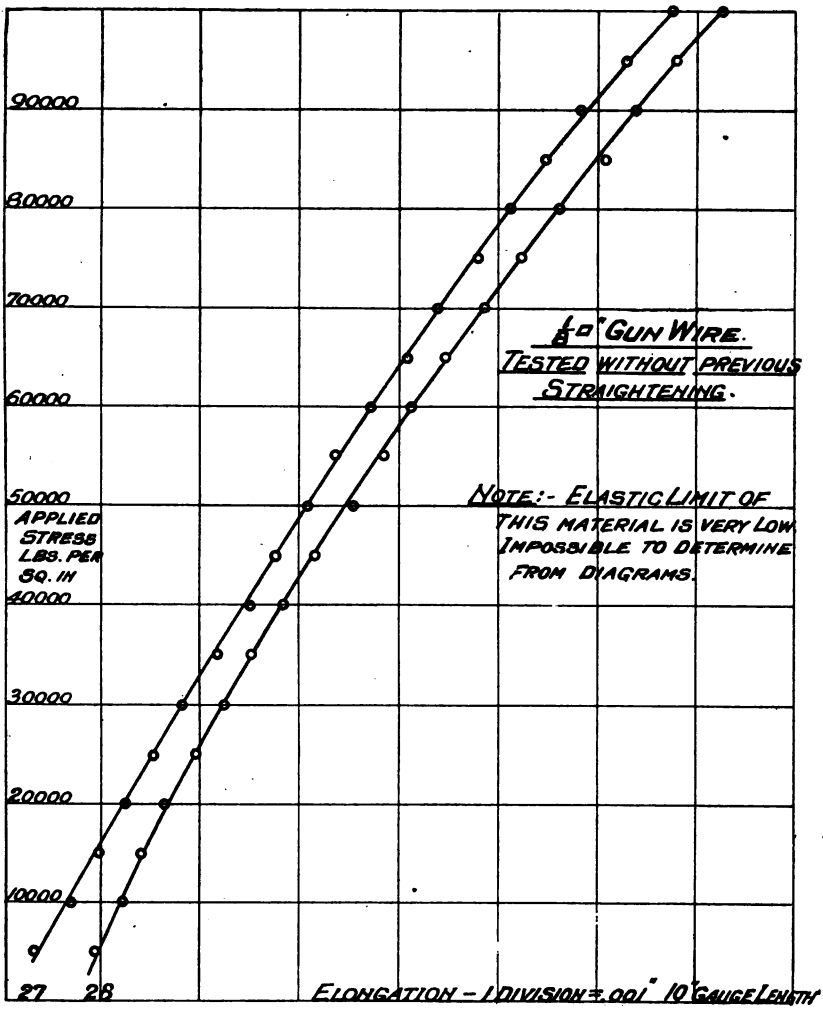
From what can be learned from the manufacturers, this wire is made by a combination of "patenting" and "drawing." The last patent annealing operation is followed by considerable reduction, so that the process by which the wire is made would in itself show that the wire was coldworked and not elastic. To be perfectly elastic, the final heat treatment operation could not be followed by any drawing operation.


90000
80000
70000
60000
50000
40000
30000
20000
10000
APPLIED STRESS LBS PER SQ. IN.
80000
80000
79000
79000
HEAT TREATED GUN WIRE.
ELONGATION-1 DIVISION = .001" 10" GAUGE LENGTH.
10
11
12
13


90000
80000
70000
60000
APPLIED STRESS POUNDS PER SQ. INCH.
50000
40000
30000
20000
75000
75000
70000
70000
HEAT TREATED GUN WIRE.
ELONGATION 1 DIVISION = .001" 10" GAUGE LENGTH.
14
15
16
17


90000
80000
70000
60000
50000
40000
30000
20000
10000
APPLIED STRESS LBS PER SQ. IN.
80000
75000
75000
75000
HEAT TREATED GUN WIRE
ELONGATION - 1 DIVISION = .001" GAUGE LENGTH 10"
18
19
20
21


90000
80000
70000
60000
APPLIED STRESS LBS. PER SQ. IN.
40000
30000
20000
10000
77000
75000
70000
10000
HEAT TREATED GUN WIRE.
22
23
24
26
ELONGATION - 1 DIVISION = .001" 10" GAUGE LENGTH.


90000
80000
70000
60000
50000
40000
30000
20000
10000
APPLIED STRESS LBS. PER SQ. IN
27
28
4-0" GUN WIRE.
TESTED WITHOUT PREVIOUS STRAIGHTENING.
NOTE:- ELASTIC LIMIT OF THIS MATERIAL IS VERY LOW IMPOSSIBLE TO DETERMINE FROM DIAGRAMS.
ELONGATION - 1 DIVISION = .001" 10" GAUGE LENGTH

PERMANENT SET EXPERIMENTS.

The following experiments were carried out, using the apparatus described below. Photograph No. 3685 shows the various parts assembled for an experiment.

The tube furnace marked "A," which had a length of 60 centimeters, was constructed from a one-half inch silica tube wound with nichrome wire, the wire being protected by alundum cement. Excessive radiation was prevented by the use of asbestos pipe covering and sheet asbestos

After the wire to be tested had been passed through the furnace, a loop was made at each end, the upper loop for attachment to a bar which rested on two crosspieces bolted to the upright guides of the large impact machine, while the lower loop served as a means of attachment to the desired weight. The rheostats, switches, and ammeter for controlling the current supply to the electric furnace are located on the table at D. Temperatures were measured by means of a platinum couple and a portable potentiometer, the potentiometer also being located on the table D.

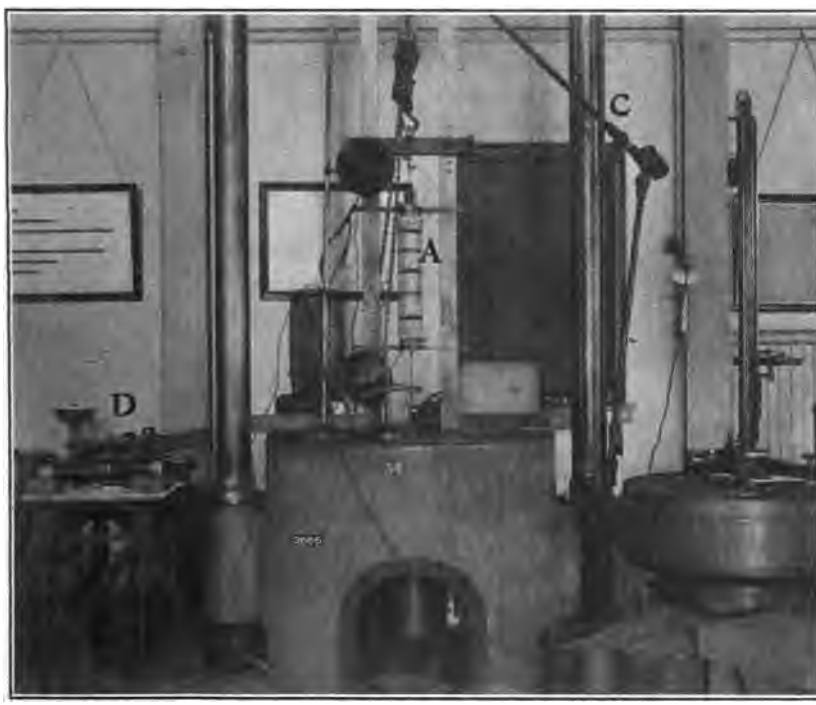
The behavior of the wire was noted by means of a cathetometer C, mounted on a heavy iron base. Fine scratches were made on the wire at both ends of the furnace tubes, and served to define the gauge length used in each experiment. A brief outline of the operations necessary for the performance of an experiment are as follows:

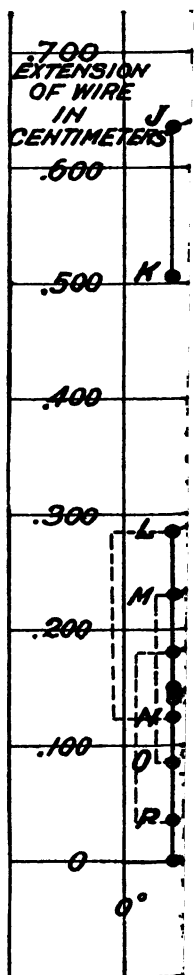
The desired wire was first passed through the furnace, the loops made at the end and the zero load suspended to the wire. The zero load was in all cases 5,250 pounds. Faint scratches were then made at each end of the furnace and the gauge length determined by the cathetometer which was so graduated that readings could by taken to 0.005 of a centimeter. As the gauge length in all cases was over 60 centimeters, this degree of accuracy of the cathetometer was all that could be desired.

After the gauge length had been determined the zero load was removed and the desired constant load to be used in the experiment was then applied to the wire. The length between the previous scratches was again determined and the difference between the two readings gave the extension of the wire produced by the load. In a great number of experiments this load was left on the wire for periods varying from 24 to 72 hours before the wire was heated. Any stretching observed under constant load was within the limits of the variations caused by changes in room temperature and instrumental errors.

The first series of experiments consisted in heating one-eighth inch square wire under a tension of 60,000 pounds per square inch to different maximum temperatures. The rate of heating was kept as near constant as possible, as was also the rate of cooling. The wire used was taken directly from the coil and was subjected to no previous heat treatment. The results from these five experiments are shown graphically on page facing 148. The abscissæ represent temperature in degrees Centigrade, and the ordinates extension of the wire in centimeters. A detailed explanation will be given of this graph so that the curves following may be more readily understood.

The condition of all the wires under the zero load at atmospheric temperatures is represented by the point B, or, in other words, the


C
A
D


.700
EXTENSION OF WIRE IN CENTIMETERS
J
.600
K
.500
.400
.300
L
M
.200
N
O
.100
R
0
0°

31082

gauge length was made when the wire had the zero weight applied. Upon application of 60,000 pounds per square inch, the wire increased in length to the point A. Current was then applied to the furnace and the temperature of the wire raised to any desired point. The curve A–C–D–E–F–G shows the increase of length of a heated section as the temperature was increased. A very decided inflection occurs in the region of C–F. At the point G, the curve becomes very nearly parallel to the Y axis from which it can readily be seen that a very slight increase of temperature would produce an enormous extension of wire. In fact, at temperatures above 450° C. the wire was very plastic and deformation proceeded very rapidly. The observation of this phenomenon at once limited the experiments to temperatures inferior to 400° C., as it was evident that such behavior in wire-wound guns would be disastrous.

To illustrate the phenomena taking place on cooling, the wire which was heated to approximately 300° C. can be considered in detail. When this wire had reached its maximum temperature the elongation had reached the point shown by the letter D on the curve. This elongation can, for convenience, be ascribed to three factors, namely, molecular readjustment (tempering), relief of previous strains due to cold work, and expansion due to heat. Upon cooling to room temperature, the extension is shown by point M. The permanent set observed is represented therefore by the distance A–M, which is 0.08 centimeter. As the original extension A–B was 0.15 centimeter the permanent set resulting was over one-half of the original extension produced by 60,000 pounds per square inch at room temperature. The 60,000 pounds per square inch load was then removed and the zero weight applied, the extension then being reduced to the point O, the permanent set under zero load being represented by the distance B–O, which was also equal to 0.08 centimeters. The permanent set figure used in this report is the permanent set resulting when the wire was under the tension used in the experiment, that is, all sets were measured by lines similar to A–M in preference to lines similar to B–O, as the latter condition would be the one found in wire-wound guns as the wire is wound under tension and takes its set presumably while under tension during an assembling or relining operation.

The lines D–M, E–L, F–J, and G–H show the course of the wire during cooling, the permanent set being measured by A–M, A–L, A–J, and A–H. One of the striking facts is that these lines are parallel or nearly so, and the fact that this condition exists enables one to determine the permanent set resulting at any temperature shown on the curve. All that is necessary to do this is to pick out the desired temperature from the curve and draw a line parallel to E–L or F–J. The permanent set can then be determined by a distance measured parallel to the Y axis similar to A–M. The parallelism of these lines is very probably due to the fact that a greater portion of any molecular transformation or relief of strains due to cold-working has taken place during the heating operation, and that in cooling the wire has followed very closely the laws of expansion and contraction due to changes of temperature.

An inspection of the data submitted by Watervliet Arsenal concerning the time of heating used in assembling and relining operations made it apparent that attempts to change the rate of cooling would

not be necessary. To further elucidate this point, the time of heating in relining the Crozier wire-wound gun was nine hours, and it seems reasonable to assume that any changes in structure or relief of strains in the wire would take place during the heating operation, and that the rate of cooling, provided that it was not sufficiently rapid as to again introduce strains, would not be of serious importance. To further illustrate this point we know that after tempering a piece of quenched steel at 600° C., additional tempering at temperatures inferior to 600° C., will produce little if any change in physical properties, unless the time of tempering at the inferior temperature be very long.

The following table is introduced to show the effect of temperature on the permanent set resulting:

Temperature (° C).	Elongation produced by 60,000 pounds (centimeter) at room temperature.	Permanent set resulting (centimeter).
234	0.145	0.035
294	0.150	0.080
351	0.140	0.145
416	0.140	0.495
455	0.150	0.975

The next series of experiments, 6, 8, and 9, were carried out to determine the influence of the rate of heating. It was shown in this experiment that the maximum rate of heating which could be obtained in the furnace employed gave results so nearly identical with those in which the rate was very slow that one rate could be used throughout the experiments.

The character used to locate the determined points in experiment 6 is ■, for experiment 8 ●, and for experiment 9 ⊡. An examination of the curve on page facing 152 will show at a glance that all the points determined lie for the various rates employed on essentially the same curve. The maximum temperature in one case was 475° C. and at this temperature the elongation was exceedingly rapid. The current was at once turned off and upon cooling down it was observed that the wire had necked down preparatory to fracture.

The following three series of tests were carried out on wire taken directly from the coil. The tension was varied, being 60,000 pounds in tests 10, 10a, 11, 12, and 13; 47,500 pounds in tests 42 to 46; and 37,500 pounds in tests 37 to 41. Bearing in mind that the two preliminary series brought to light that the rate of cooling need not necessarily be varied; secondly, the rate of heating was a factor exceedingly hard to properly vary; and third, that when the rate of heating did not exceed approximately three hours it was without serious influence, the following course was adopted.

The procedure consisted in heating the wire to the desired temperature, holding it at this temperature six hours, and then cooling in the furnace. It can be safely considered that this represents the most extreme condition to be met in the assembling or relining of a wire-wound gun, and furthermore, it will represent also as favorable a condition as can be hoped to be attained especially on guns of large caliber.

Considering in detail the tests in which the load was 60,000 pounds, page 152, it is to be noted that elongations were produced by holding six hours at the maximum temperature. Taking the wire which was heated to 221° C. for example, the extension produced by the original load at room temperature is represented by the line A–B. The extension produced by heating is shown by the curve B–C. The extension produced by holding six hours at the maximum temperature is shown by the line C–D. The course of the wire on cooling is shown by the line D–E, and the permanent set resulting is measured by the distance B–E. To offset any objection which may be raised concerning the adoption of methods in which the assembling or relining operation is carried out quickly and the gun does not have to be held at the maximum temperature, it is desirable to state that almost the entire extension which occurs in the wire, especially at low temperatures, takes place on heating up and the first few minutes after the wire has been at the maximum temperature. This indicates that change of structure and relief of strains take place very rapidly, and a long time is not required for this readjustment. The points D–G–J–M and P have been connected in a curve so that the permanent set resulting from heating to a given temperature and holding at this temperature six hours can be determined in the manner previously described, that is, by drawing a line parallel to the cooling lines such as M–N, P–Q, etc.

The curve on page 153, plotted from tests in which the constant tension was 47,500 pounds, differs from the previous curve in that the permanent set occurring at a different temperature, is decidedly less. This is largely brought about by the fact that the six-hour treatment at the maximum temperature did not produce so much effect in the wires on which the load was small. The same remarks will apply to the experiments which are plotted on page 154 in which the load was 37,500 pounds per square inch. With this tension of winding, very small sets would occur when the temperature was inferior to 221° C. This would point to the fact that if our present construction is continued, the proper course to pursue would be to use a minimum winding tension with as low assembling and relining temperatures as possible.

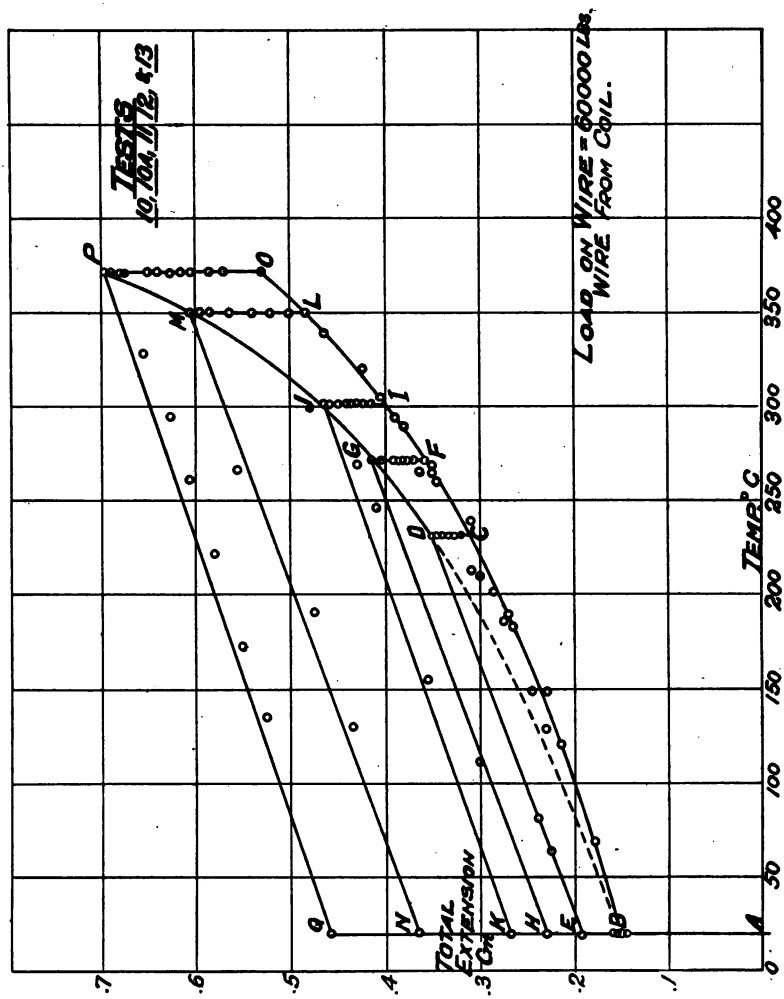
The following table is introduced to show the influence of the constant load on the resulting permanent set:

Temperature (° C.).	Per cent set of original gauge length.		
	37,500 pounds.	47,500 pounds.	60,000 pounds.
228 222 230	0.033	0.059	0.075
271 271 271	.083	.108	.142
300 300 302	.125	.142	.192
351 350 350	.208	.258	.333
373 373 373	.275	.317	.542

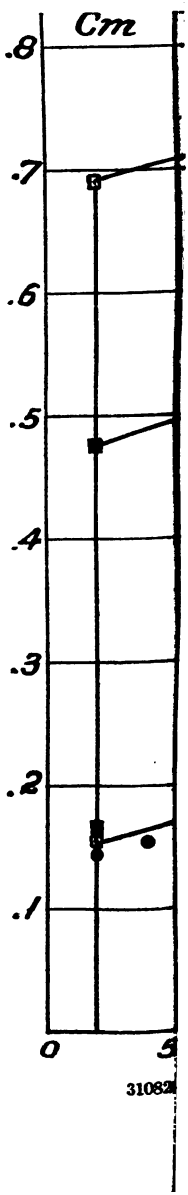
The per cent elongation produced by the load in each case was approximately as follows:

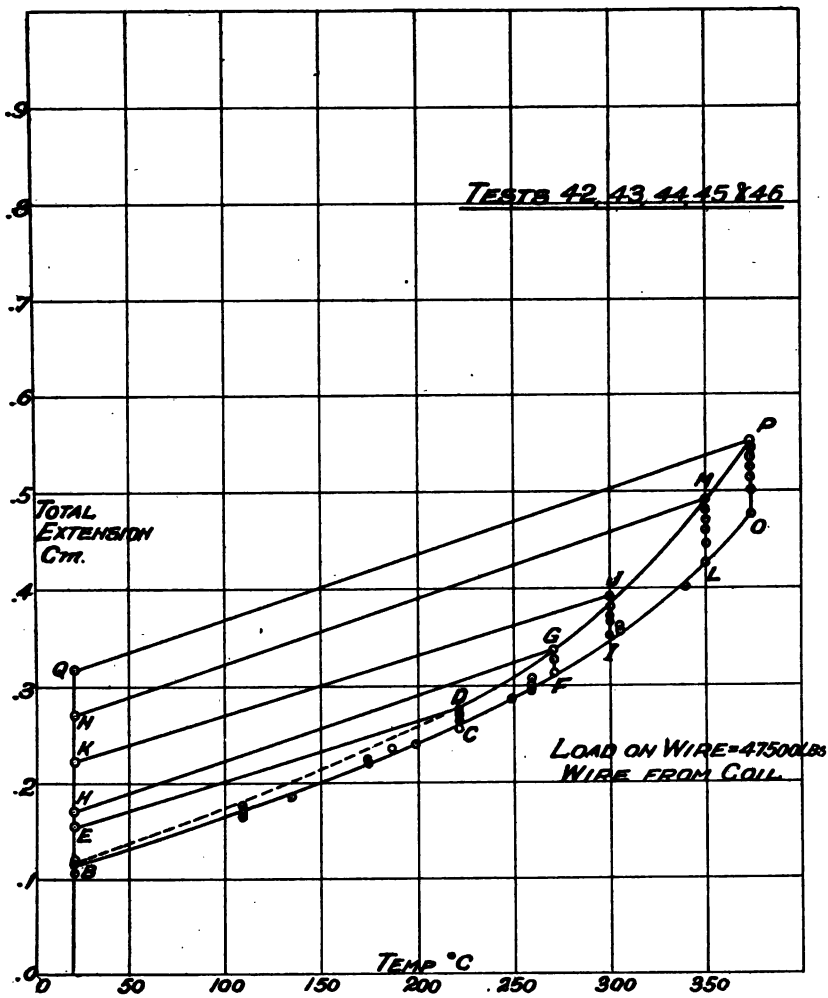
	Per cent.
60,000 pounds	0.220
47,500 pounds	.170
37,500 pounds	.130

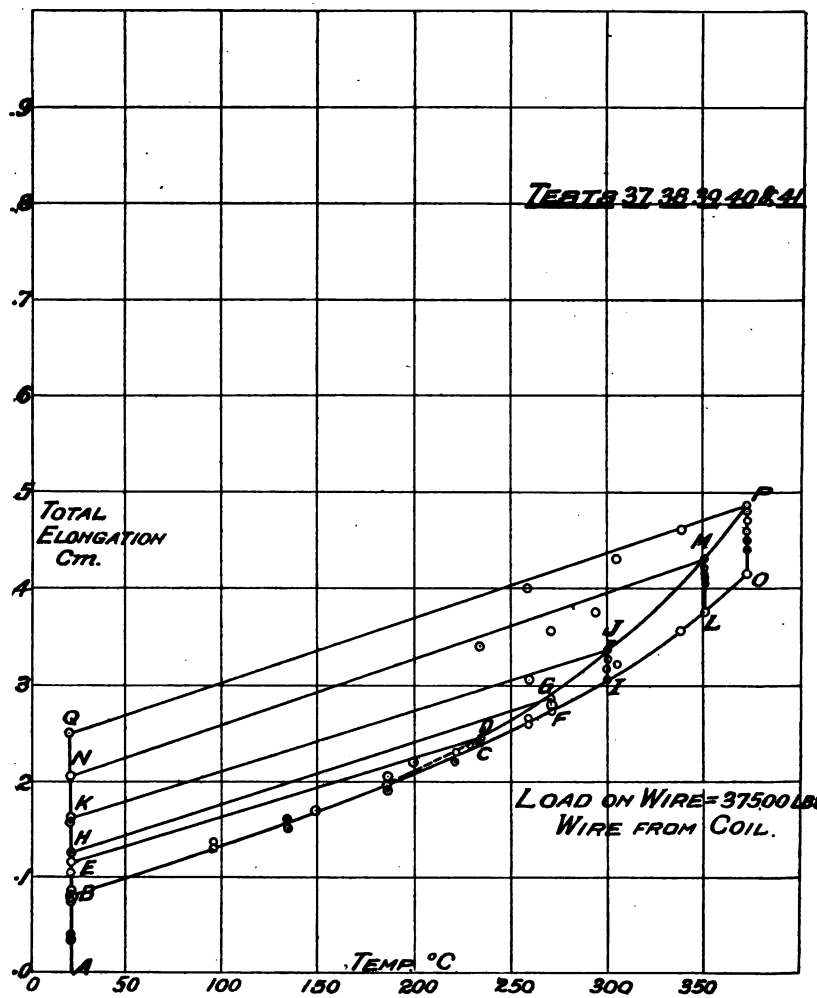
It is very evident that increasing load and increasing temperature both increase the permanent set.



From an inspection of the curves, the following general conclusion seems justified. If the present practice of using square gun wire is continued and a cold-worked wire is used, the winding tension should be as low as possible and the temperature of assembling or relining very low. If the tension of winding is 37,500 pounds per square inch or less, and the assembling or relining temperature less than 150° C. or 302° F., the permanent set in all probability would be less than 10 per cent of the original extension of the wire.


Cm
.8
.7
.6
.5
.4
.3
.2
.1
0
5
31082


TESTS 42, 43, 44, 45 & 46
TOTAL EXTENSION Cm.
LOAD ON WIRE = 47500 Lbs
WIRE FROM COIL
TEMP °C
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
0
50
100
150
200
250
300
350
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q


TESTS 37 38 39 40 & 41
TOTAL ELONGATION Cm.
TEMP. °C.
LOAD ON WIRE = 37500 LBS.
WIRE FROM COIL.
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
.0
.1
2
3
4
5
6
.7
.8
.9
0
50
100
150
200
250
300
350

Tests 16 and 17, curve on page 157, were carried out on the wire which was annealed at 600° C. one hour in the coil, should be compared with curve B–F–G–H, page 152, and curve B–O–P–Q, page 152. This treatment has served to materially lessen the permanent set resulting by heating to a given temperature under a constant tension. This is largely due to the fact that a molecular readjustment was brought about by the previous anneal at 600° C. This anneal was not sufficiently high, however, to give us a wire having an elastic limit when straight which would be superior to the load applied to the wire at all the temperatures in the experiment. A similar test was carried out on wire which had been annealed at 450° C. for one hour. The permanent sets resulting were similar to those experienced in the wire which had been annealed at 600° C. The curves for tests 16 and 17, page 157, and tests 14 and 15, page 156, make a very interesting comparison.

[Load on wire=60,000 pounds.]

Treatment.	Per cent set of original gauge length.	Temperature (° C.).
Wire from coil	0.142	271
Do	.542	373
Annealed 1 hour at 450° C. in coil	.050	271
Do	.257	373
Annealed 6 hours at 600° C. in coil	.058	271
Do	.242	373

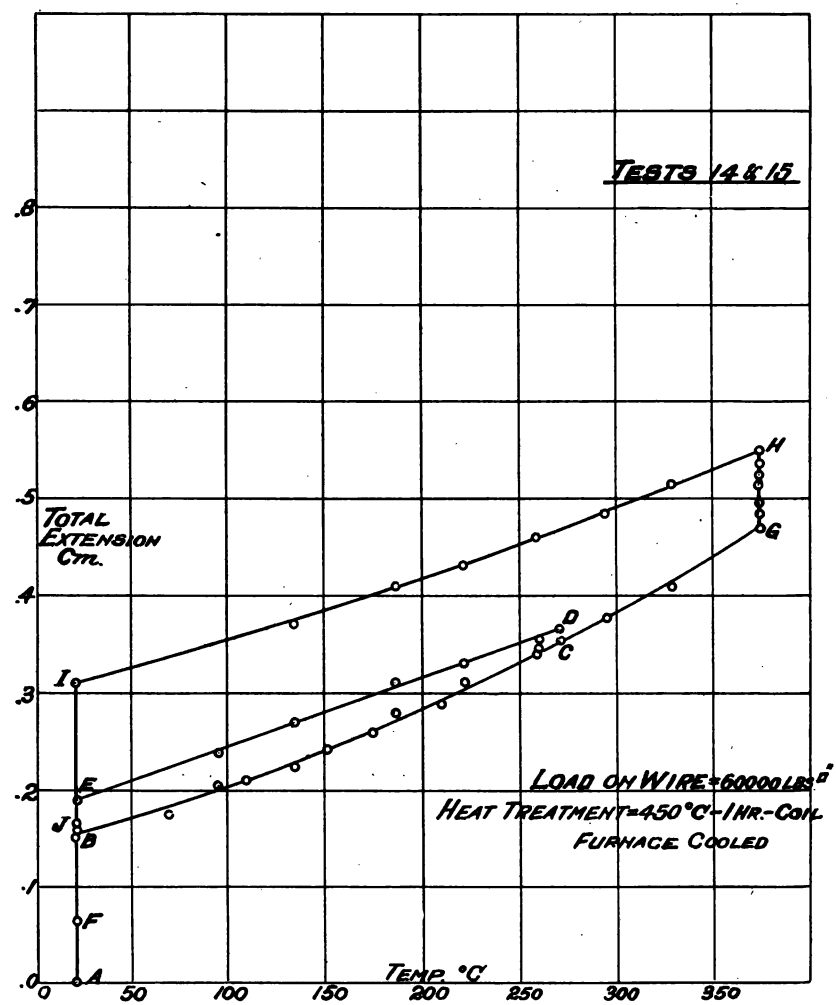
The above table shows the decided improvement brought about by annealing the wire below the critical range.

Test 19, page 158, was performed on a piece of wire which had been heated to 800° C. in the coil and cooled in air. The first point to be noted in connection with this test is that the extension A–B produced by the 60,000 pounds per square inch at atmospheric temperature, is approximately five times that observed when the wire is taken from the coil. This is explained by the fact that although this treatment had made the wire perfectly elastic in the coil form, the mere operation of straightening is sufficient to take the outside fibers beyond the elastic limit. This was not enough cold-worked, however, to stiffen the wire, as is the case of the wire on the reel as received, and consequently an exceedingly great elongation was obtained.

The curve on heating was very straight until a temperature of approximately 350° C. was reached, when a decided deflection occurs. The permanent set in this wire was measured by the distance B–B. Although the ratio of the line B–E with the line B–A is small, and a study of the ratio figures might lead one to think that this was a desirable treatment, such is not the case, as it is very evident that the wire was taken beyond its elastic limit by the operation of straightening, and consequently this would be the case if such a wire was wound on a gun from a previous straight condition.

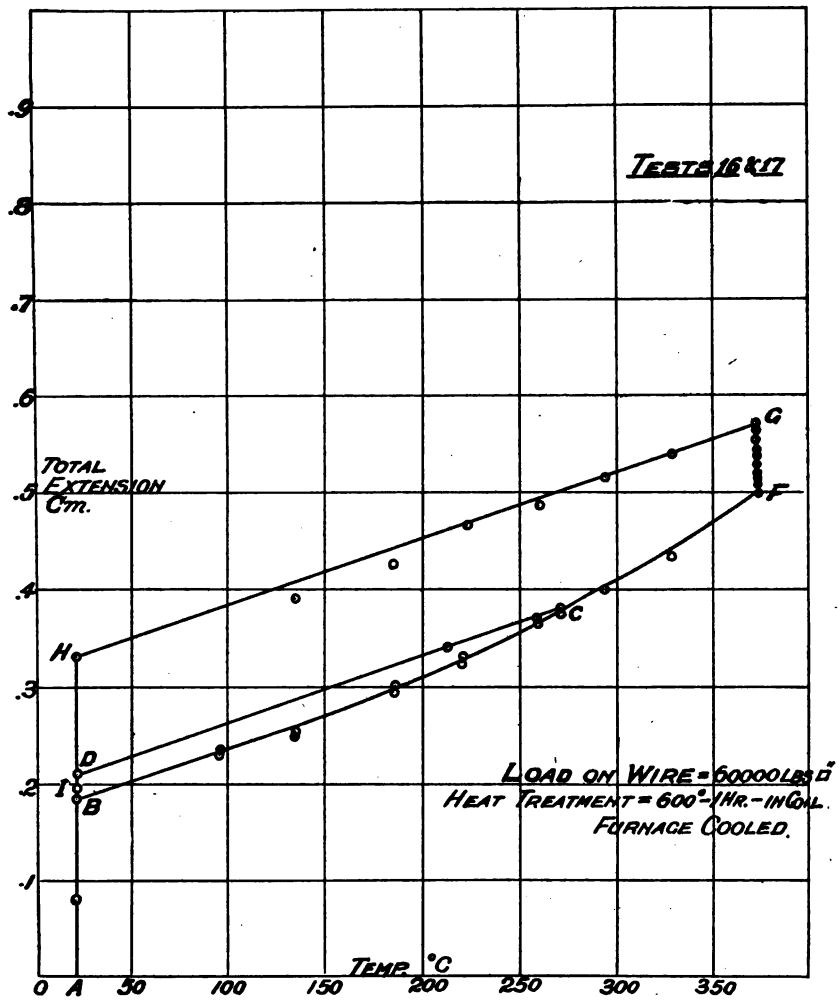
Test No. 18, curve on page 159, was carried out on wire which was heat treated so that it was in the straightened condition. This was the first of a series of tests which was carried out on similar wires. The physical test on this wire gave an elastic limit of 65,000 pounds, and as the load on the wire was 60,000 pounds, it is very reasonable to suppose that at a very low temperature the elastic limit

of the wire was brought to a point inferior to that of the load on the wire, and elongation ensued. The permanent set measured by the distance B–E was very great, and it was evident that if heat-treated wire was used for winding guns it must have an elastic limit of such a value that the heating operation necessary for assembling or relining will not lower it beyond the maximum stresses occurring in the wire when the gun is at rest.



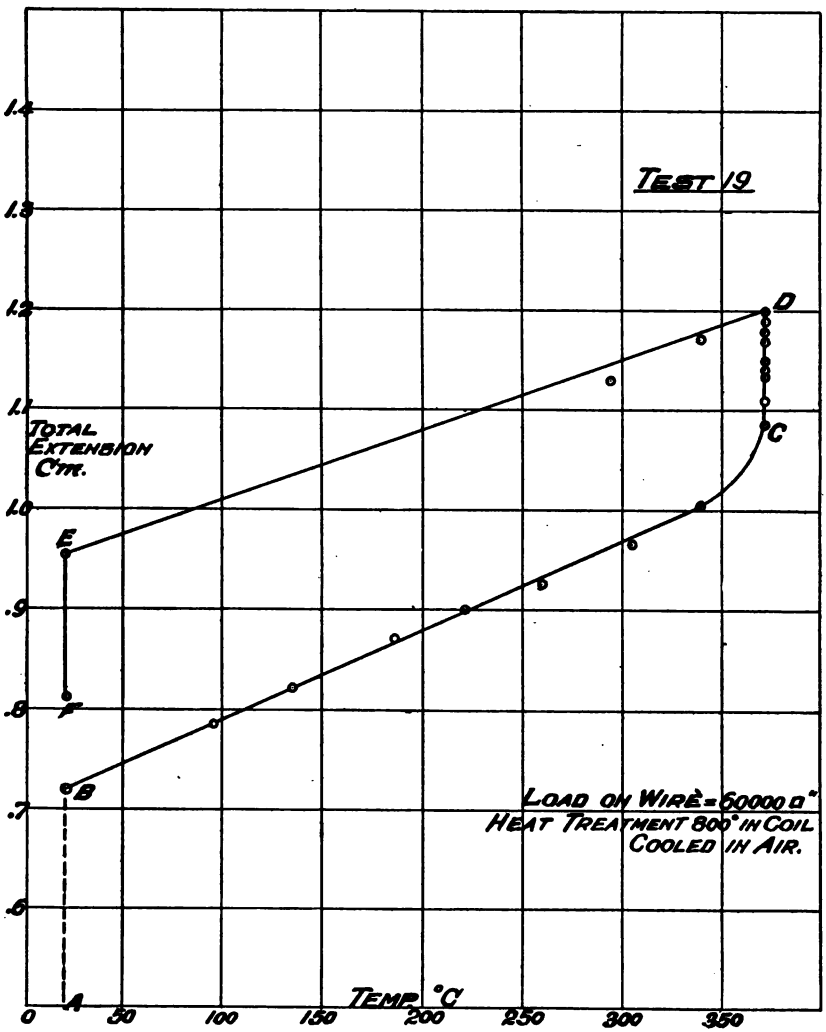
Tests Nos. 20 and 21, shown graphically on page 160, were conducted on wire having an elastic limit of approximately 70,000 pounds per square inch. The course of this wire during heating was very interesting. At some point between 100 and 150° C. the elastic limit of the material must have become inferior to the load on the wire, and a rapid stretching resulted. At some temperature slightly greater than 200° C. the wire seemed to stiffen and much less stretching was observed. The permanent set, as might be expected from

such behavior, was very great. The same phenomena were observed on the wire which was heated to 271° C. and held six hours. The break occurring between 100 and 150° C. was not so marked, but a certain stiffening did occur between 200 and 250° C., as was the case with the other wire. These experiments were conclusive thet the factor of safety of 10,000 pounds was not at all sufficient at insure that the elastic limit would not be exceeded at some timo during the heating operation.



Tests No. 22 and No. 23, curves on page 161, were carried out on wire whose elastic limit was in the neighborhood of 75,000 pounds per square inch. These wires behaved very much better than the ones having a lower elastic limit, and the decided break in the curve is absent. Less set was observed than in wire similarly tested as taken from the coil.

Tests No. 47 and No. 48, curves on page 162, show similar phenomena to that exhibited by the curves of experiments No. 20 and No. 21, page 160, or in other words, the elastic limit of the wire was reduced to a point below that of the applied load and rapid stretching occurred. This rapid stretching was followed by subsequent stiffening of the wire. The wire used in this test had an elastic limit of

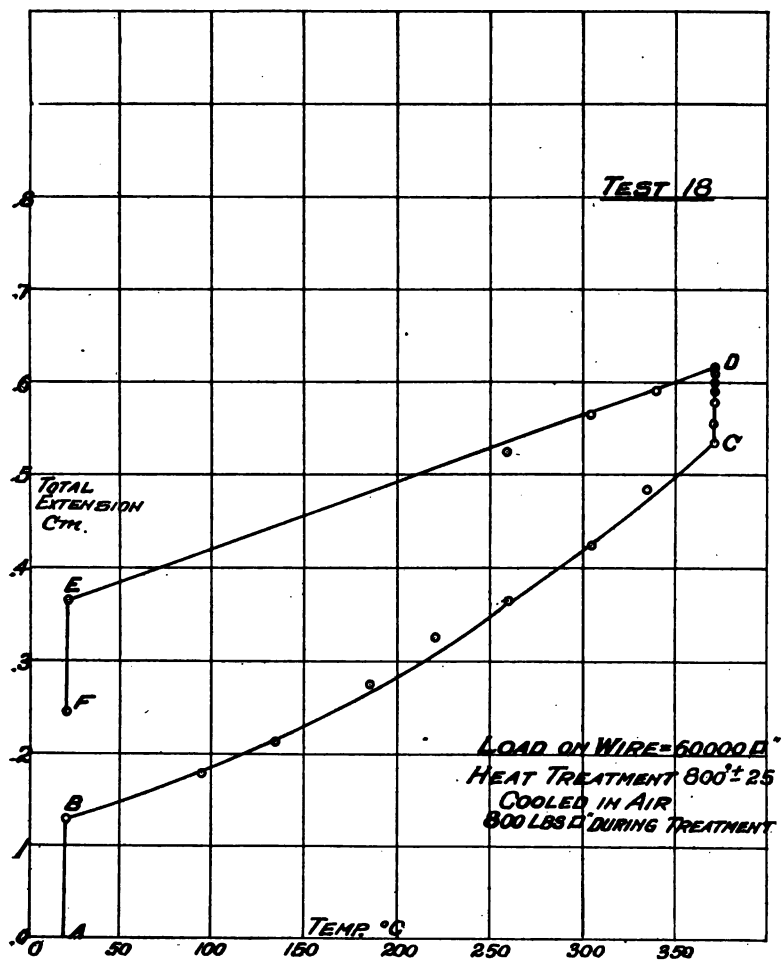


79,000 pounds per square inch, and was straightened in the heat-treating operation. From the character of the curve, large permanent sets would be expected at any temperature greater than 200° C.

Tests Nos. 49, 50, and 51 were conducted on heat-treated wire having an elastic limit of 75,000 pounds per square inch, and the results are shown graphically on page 163.

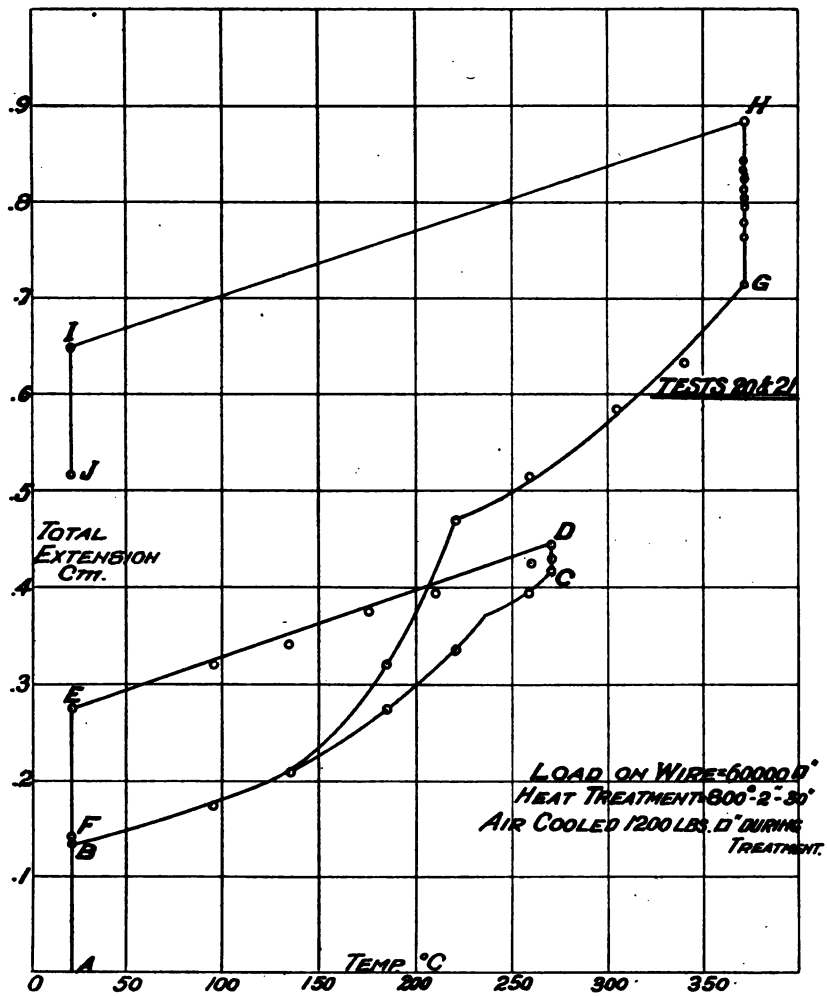
A comparison of the permanent sets resulting from this experiment and those resulting from heating the cold-drawn material to the same temperatures under the same loads is shown below:

Wire used.	Temperature (° C.).	Per cent set of original gauge length.
Wire from coil	373	0.190
Heat-treated wire	373	.050
Wire from coil	300	.142
Heat-treated wire	300	.015
Wire from coil	271	.108
Heat-treated wire	271	.010



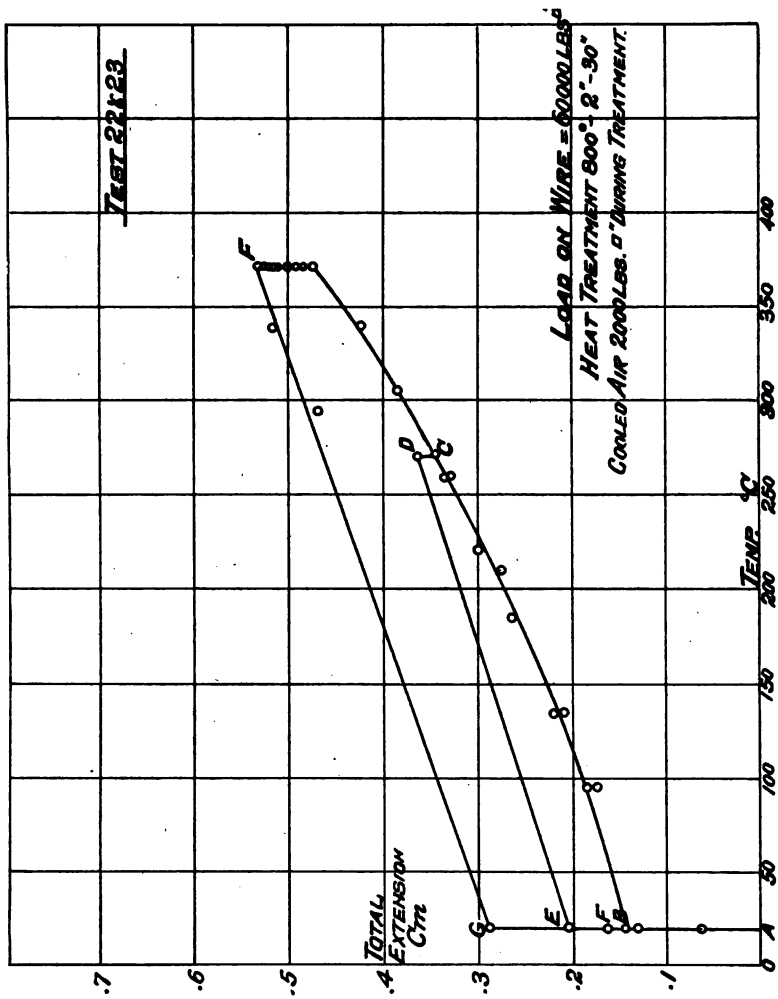
In the experiments where the wire was not heated to more than 300° C. the permanent set in the heat-treated wire was approximately 10 per cent of the cold-worked wire.

Experiments Nos. 53 and 54, the results of which are shown graphically on page 164, were conducted on wire annealed at 450° C. for one hour, or in other words, on wire annealed below the critical point. The permanent sets obtained were quite large but were smaller than those obtained on wire taken directly from the coil and heated to the same temperatures under constant load.



In tests Nos. 24 and 25, page 165, the wire used had an elastic limit of 80,000 pounds per square inch, and as the load on the wire was 37,500 pounds per square inch, a good margin of safety existed between the load and the elastic limit. The sets observed were very small and attention is invited to the previous curve shown on page 164, representing test made on wire from the coil. A decided improvement has resulted by heat treating the wire in regard to its

taking permanent sets when heated under tension. In fact, the set obtained by heating the wire to 271° C. and then holding for six hours is so small that it could probably be ascribed to errors occurring in the experiment. The direction of the line B–C–D, curve 43, page 153, as compared with the direction of the line B–C–F–I–L–O, page 153, is evidence in itself that the molecular readjustments occur-

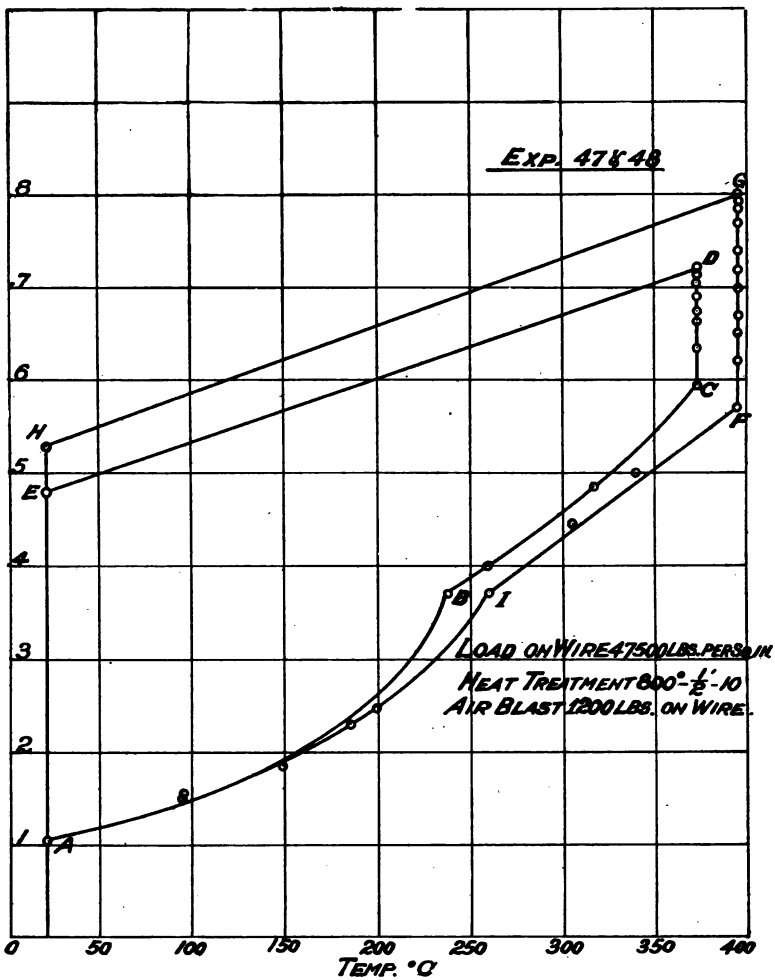


ring on heating in the treated wire are decidedly smaller, if present at all.

Tests 26 and 27, page 166, tests 28 and 29, page 167, tests 30 and 31, page 168, and tests 32 and 33, page 169, are all similar to the experiments previously descrived. The physical properties of the wire used can be obtained by reference to the table facing page 170.

The facts to be deduced simply confirm those previously discussed, namely, that the wire when heat treated so that its elastic limit at all stages will be superior to the load applied to the wire, will give a decidedly less permanent set upon test than wire similarly tested in the cold-worked condition.

The following tables give a record of all the significant tests and the data obtained therein.

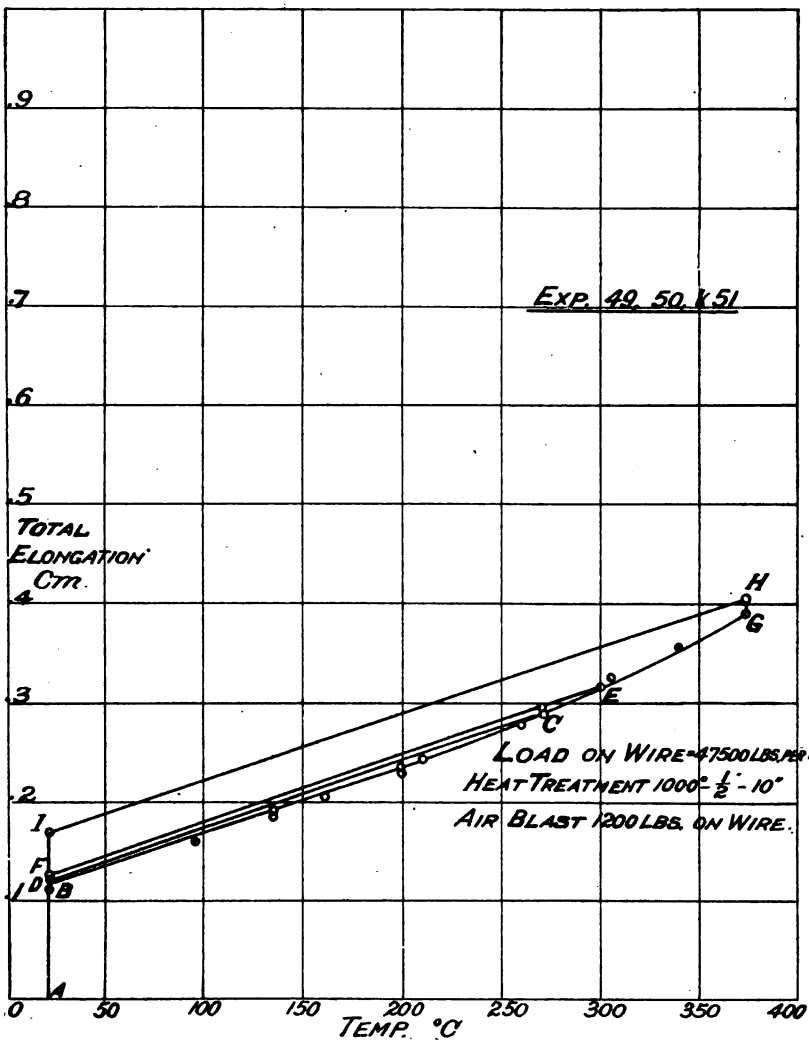


The first column shows the number of the test, the second column shows the history of the wire used in the test, namely, whether it was tested as received or whether it had been subsequently treated at this arsenal. The next two columns show the physical properties of the wire which were determined in the customary manner by the use of an extensometer on a section approximately 30 inches long with a gauge length of 10 inches.

The column headed "Load on wire during test" indicates the constant load employed when the wire was heated in order to determine the permanent set occurring.

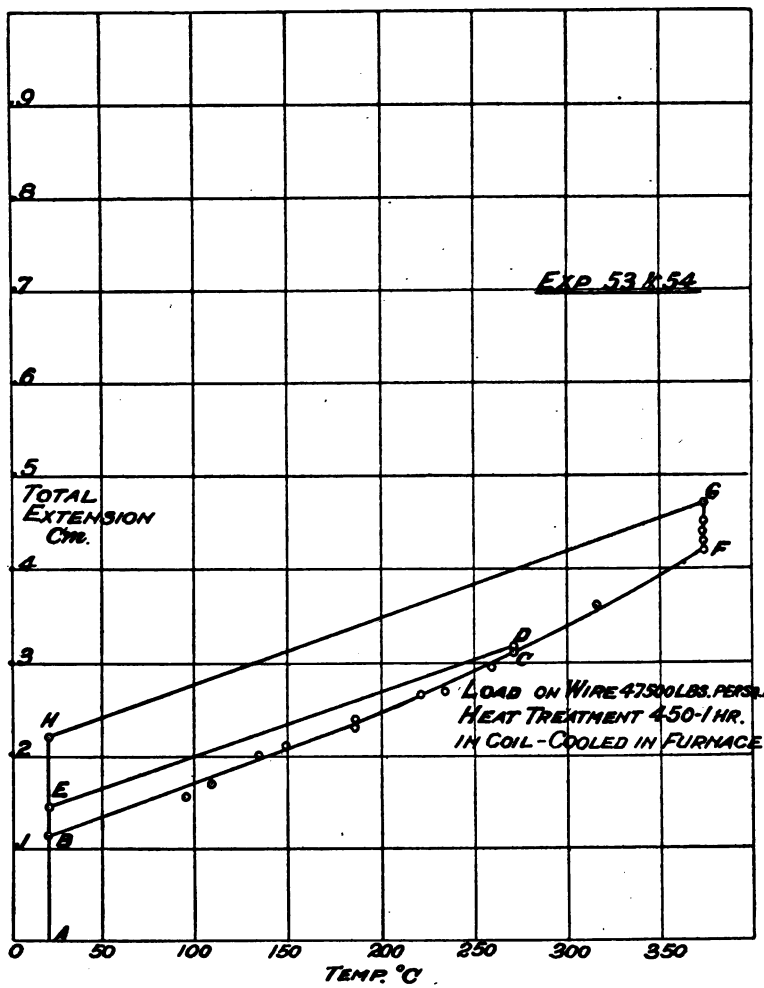
The column headed "Per cent elongation produced by load" refers to the elongation produced by the constant load at atmospheric temperatures.

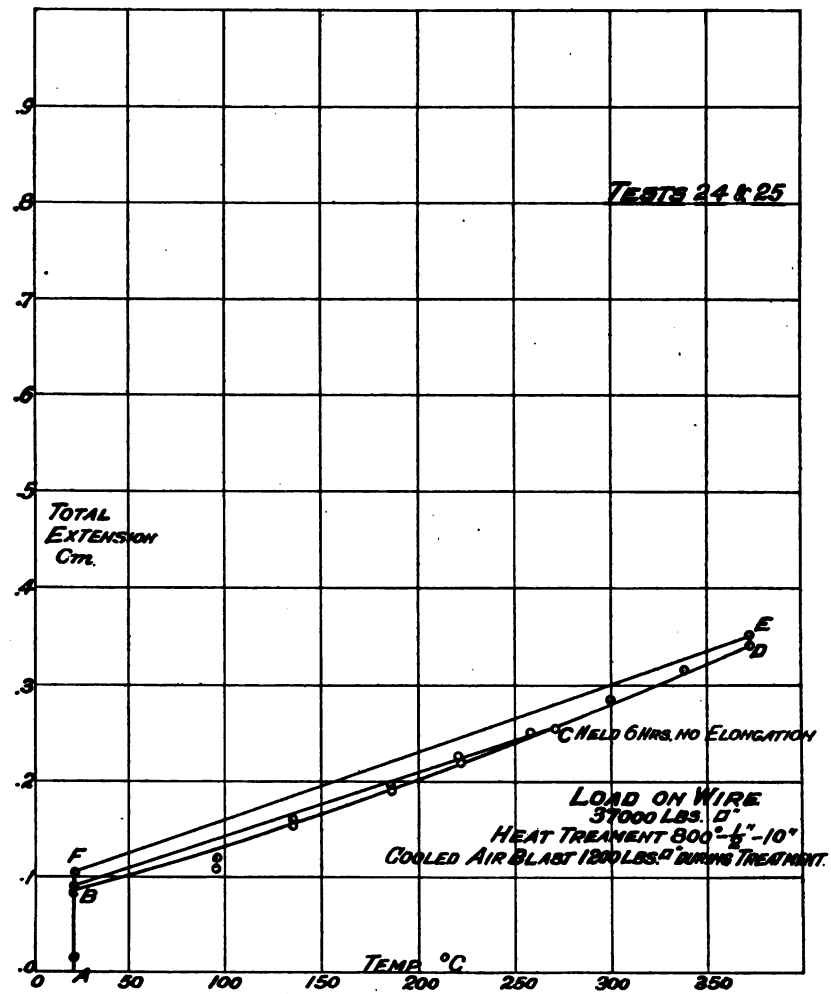
The columns headed "Time of heating at maximum temperature," "Time at maximum temperatures," "Time of cooling," and "Gauge length" each are self-explanatory. The "Elongation in centimeters

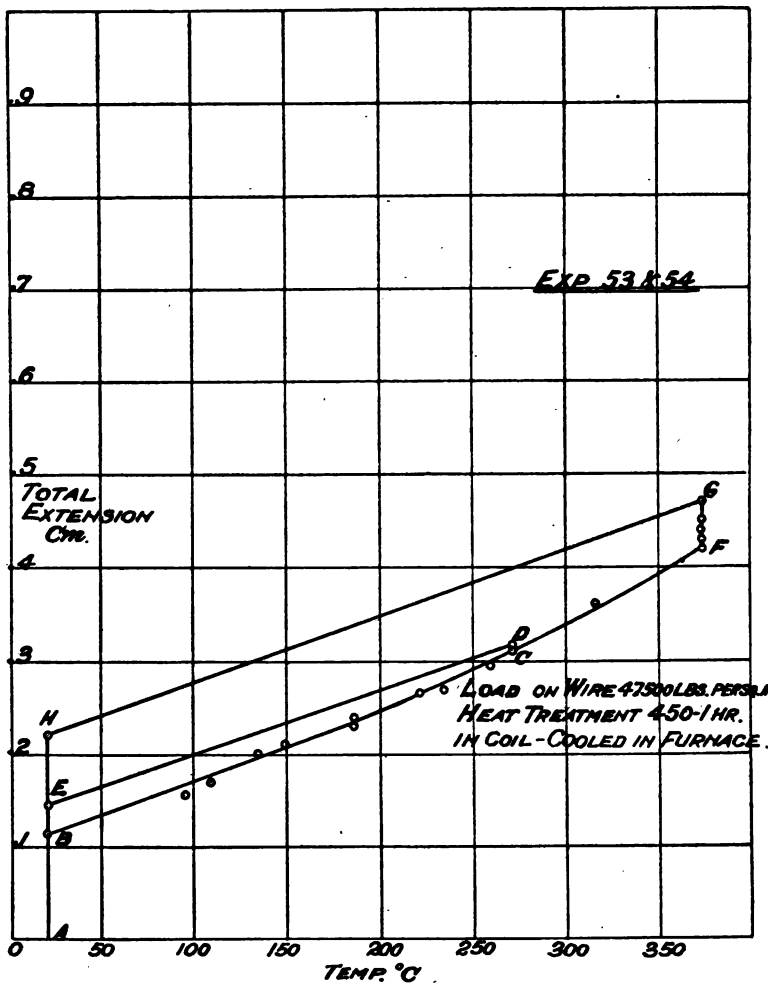


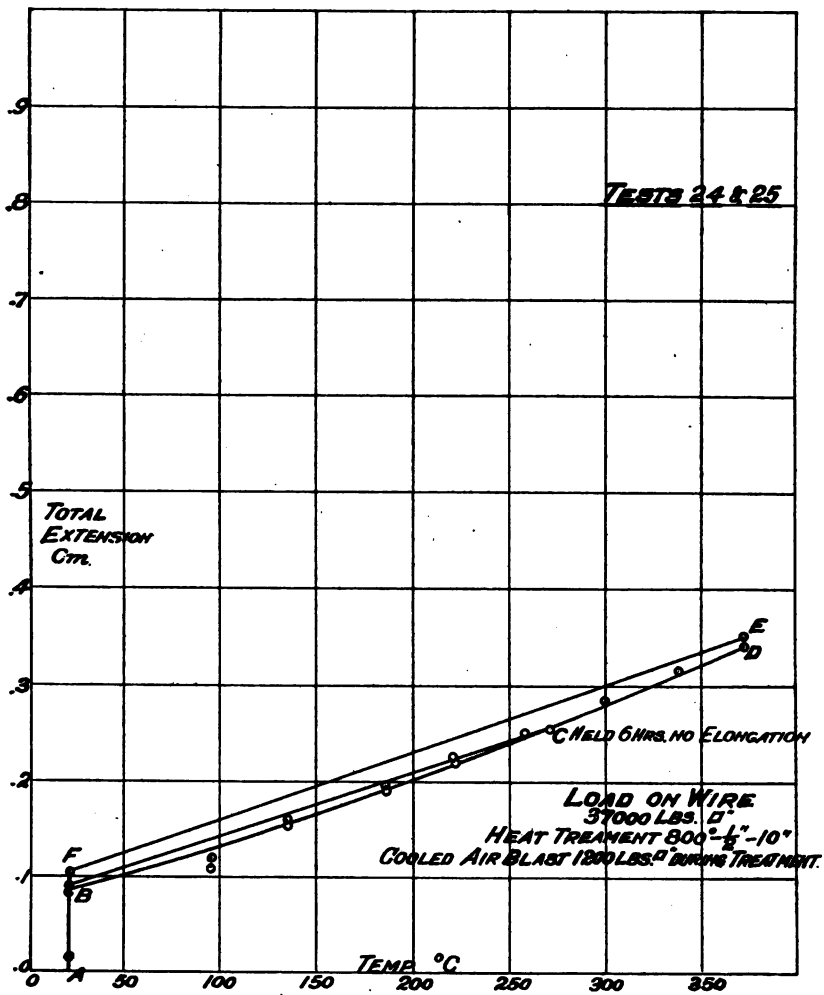
during heating" refers to the elongation produced in the wire by heating from atmospheric temperature to the maximum temperature employed in the experiments.

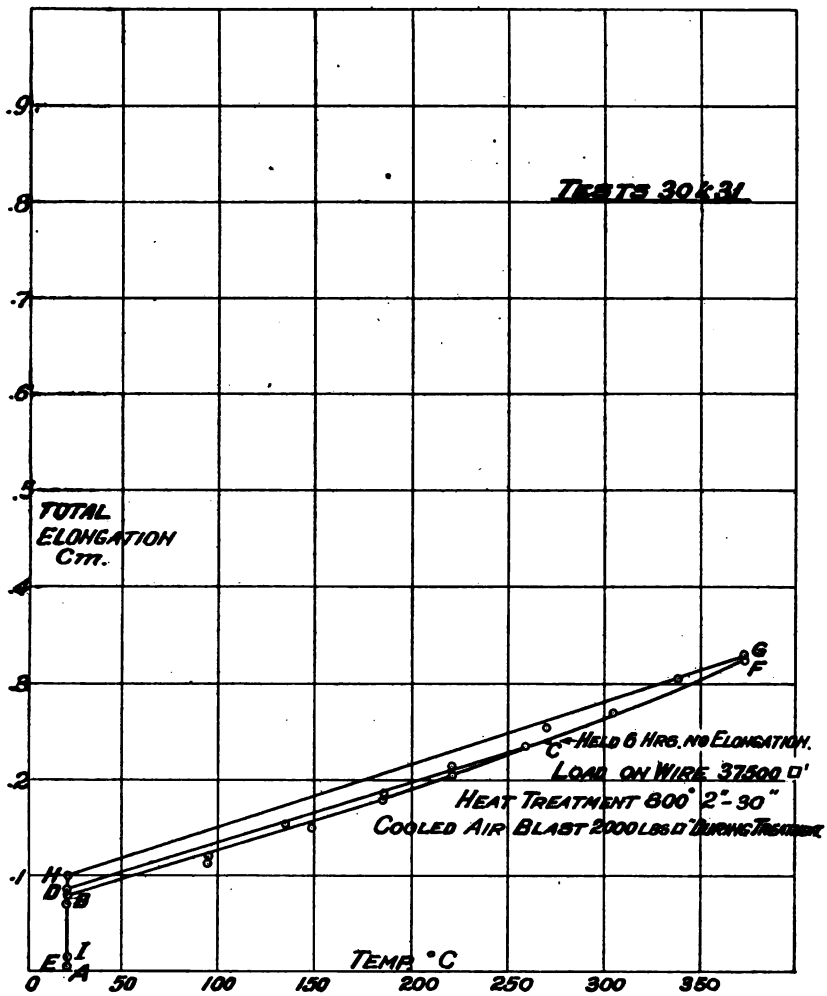
"Elongation in centimeters at maximum temperature" refers to the elongation produced by heating the wire at the maximum temperature for the time specified in the column headed "Time at maximum temperature.

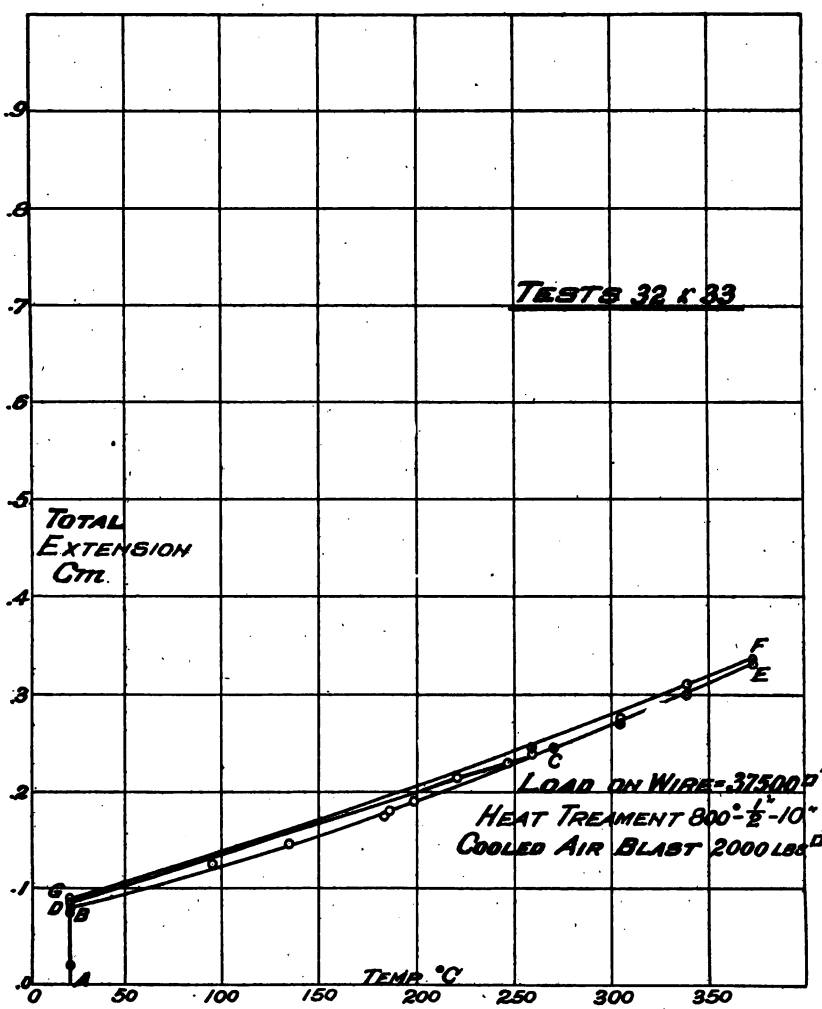

EXP. 53 & 54
TOTAL EXTENSION Cm.
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
50
100
150
200
250
300
350
TEMP. °C
LOAD ON WIRE 47500 LBS. PER SQ. IN.
HEAT TREATMENT 450-1 HR.
IN COIL - COOLED IN FURNACE.
A
B
C
D
E
F
G
H


TESTS 24 & 25
TOTAL EXTENSION Cm.
°C WELD 6 HRS. NO ELONGATION
LOAD ON WIRE 37000 LBS. Cº
HEAT TREATMENT 800°-½"-10"
COOLED AIR BLAST 1200 LBS.Cº DURING TREATMENT.
TEMP. °C.
A
B
C
D
E
F
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
0
50
100
150
200
250
300
350


EXP 53 & 54
TOTAL EXTENSION Cm.
LOAD ON WIRE 47500 LBS. PER SQ. IN.
HEAT TREATMENT 450-1 HR.
IN COIL - COOLED IN FURNACE.
TEMP. °C
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
50
100
150
200
250
300
350
A
B
C
D
E
F
G
H


TESTS 24 & 25
TOTAL EXTENSION Cm.
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
E
D
°C HELD 6 HRS. NO ELONGATION
LOAD ON WIRE 37000 LBS. ☐"
HEAT TREATMENT 800° - 1/2" - 10"
COOLED AIR BLAST 1800 LBS.☐" DURING TREATMENT.
F
B
A
TEMP. °C
0
50
100
150
200
250
300
350


TESTS 30 & 31
TOTAL ELONGATION Cm.
.9
.8
.7
.6
.5
.4
.3
.2
.1
G
F
C
HELD 6 HRS. NO ELONGATION.
LOAD ON WIRE 37500 D'
HEAT TREATMENT 600° 2"-30"
COOLED AIR BLAST 2000 LBS D' DURING TREATMENT
H
D
B
E
I
A
TEMP °C
0
50
100
150
200
250
300
350


TESTS 32 & 33
TOTAL EXTENSION Ctn.
LOAD ON WIRE=37500 D°
HEAT TREAMENT 800°-½"-10"
COOLED AIR BLAST 2000 LBS D°
TEMP. °C
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
0
50
100
150
200
250
300
350
A
B
C
D
E
F
G

31082—18——19

The column headed "Per cent set of original gauge length requires some explanation. It is very evident from the previou description of the apparatus employed that the gauge marks on th wire must fall on the outside of the furnace or, in other words, th entire gauge length was not heated. The length of the furnace wa 60 centimeters, and although a decided temperature gradient existe at the ends of the heating unit, 60 centimeters was used as the bas in computing the per cent set of the original gauge length. As th temperatures were measured in the middle of the tube and from ex periment it was determined that not over 40 centimeters were a the maximum temperature, all of these figures will be low, or in other words, a greater permanent set would have occurred if the entire gauge length could have been uniformly heated.

A column has been introduced marked

$$\text{Ratio of } \frac{\text{per cent set after cooling.}}{\text{per cent elongation produced by load.}}$$

This ratio gives a very convenient means of comparing the effecitveness of any heat treatment employed in lessening the set or the influence of any factor in producing a set. In case the per cent set after cooling is zero, the value of the ratio will be zero. When the value of the ratio is one, the wire has acquired a permanent set equal to the original elongation produced at room temperature by the applied load. If the wire is free to change in length, this ratio will also convey an idea of the amount by which the winding tension will be lessened, due to any heating operation in a gun.

As experiments have been previously discussed in connection with the curves submitted, no further remarks need be made from the table. If any curve is of particular interest, the significant data can be found at once by reference to this table.

In the following table the several experiments have been arranged in order of the value of the ratio $\frac{\text{per cent set after cooling.}}{\text{per cent elongation produced by load.}}$ As previously pointed out, this ratio is a convenient means of comparing the permanent set taken by the wire during the course of an experiment. When the value of the ratio is 0, no permanent set was present, and when the value of the ratio was 1, the permanent set observed in the wire at the close of the experiment was equal to the elongation produced by the load in the particular experiment considered. The maximum value which this ratio could reach in assembling or relining operations could not at the present time be determined, although it is very evident that the computed compression of the bore will not be retained when the value of the ratio is greater than zero.

The first four experiments in the list,—27, 25, 31, and 33,—give a maximum value for this ratio of 0.068. Experiment No. 27 is the only one in which the value of the ratio is zero. Consideration of these four experiments shows, first, that the maximum temperature of heating did not exceed 271° C. or 520° F., second, the load in pounds per square inch on the wire is 37,500 pounds, and third, which is in all probability the most important, the wires were all heat treated,

had a true elastic limit, and were used in the permanent set experiments without the necessity of being straightened, thus insuring a uniform fiber stress.

Previous experiments on the influence of temperature on the elastic limit indicate that an increase of temperature causes a decrease in the value of the elastic limit. All of the wires used in the first four experiments had an elastic limit of approximately 80,000 pounds per square inch. The inevitable conclusion would be that at no time during the course of the experiments did the temperature reach a value which would reduce the elastic limit of the wire to a point inferior to the constant load under which the wire was being heated.

The next three experiments in order are 51, 29, and 50; experiment No. 50 showing the ratio value of 0.155. This was also a heat-treated wire and the constant load used in the experiment was 47,500 pounds.

Experiments Nos. 15 and 17 show a ratio value of 0.21. These two experiments are of particular interest when compared with experiment 10a, in which the ratio value is 0.65. The conditions of the two experiments were identical with the exception that the wire used in experiments 15 and 17 had previously been annealed, in one case at 450° C. and the other at 600° C., whereas the wire used in 10a was taken directly from the coil and represents the condition of the wire on our present wire-wound guns. It is evident that annealing the wire at 450° C. was of material benefit, as the permanent set resulting by the same treatment under the same load was approximately one-third that obtained with the untreated wire.

Test No. 32, showing a ratio value of 0.22, differs from experiment No. 31, showing a ratio value of approximately 0.07, in so far as the maximum temperature of heating was approximately 100 degrees higher than experiment No. 31. With other conditions constant, an increase in the temperature of heating of approximately 100 degrees has increased the resulting permanent set approximately three times. This fact would have no direct bearing on the possible relining temperatures to be used in guns already manufactured, as the wire in both of these experiments was heat treated in such a way that the true elastic limit had been developed.

Experiments Nos. 32, 41, and 24 also make an interesting comparison, the value of the ratio being approximately the same in the three experiments. Experiments Nos. 32 and 24 were carried out on heat-treated wire with the known true elastic limit, the maximum temperature used in the experiments being 373° C. Experiment No. 41 was carried out on wire taken from the coil as received from the manufacturer, and gave the same permanent set when heated to only 228° C. Consideration of these three experiments alone shows a most pronounced benefit resulting in the use of a wire which was in an elastic condition and not cold drawn.

Such comparisons as outlined above can be made in great number from the table under discussion. This, however, is not considered essential, since the main facts are evident and can be set forth as follows:

To reduce the value of the ratio to zero or nearly so:—

First. The temperature to which the wire is heated should be as low as possible.

Second. The tension on the wire should be reduced to the lowest possible value.

Third. The wire should be in a perfectly elastic condition and not cold worked.

The first two factors can be brought about in future design, and the last factor, which is by far the most important, can be brought about by modifying the specifications, changing the shape of the wire from a square to a ribbon form, and demanding a heat-treated wire in a sorbitic condition.

TEST ARRANGED IN ORDER OF INCREASING VALUE OF RATIO.

Ratio: $\frac{\text{Per cent set after cooling.}}{\text{Per cent elongation produced by load.}}$

No. of test.	Ratio: Per cent set after cooling. / Per cent elongation produced by load.	Maximum temperature of heating (° C.).	Load (pounds).	Treatment.
27	0.000	271	37,500	1,000—$\frac{1}{2}$—10; air blast up; 1,200 pounds on wire.
25	.064	271	37,500	800—$\frac{1}{2}$—10; air blast down; 1,200 pounds on wire.
31	.068	271	37,500	800—2—30; air blast up; 2,000 pounds on wire.
33	.068	271	37,500	800—$\frac{1}{2}$—10; air blast up; 2,000 pounds on wire.
51	.104	271	47,500	1,000—$\frac{1}{2}$—10; air blast up; 2,000 pounds on wire.
29	.147	271	37,500	800—$\frac{1}{2}$—10; air cooled; 2,000 pounds on wire.
50	.155	300	47,500	1,000—$\frac{1}{2}$—10; air blast up; 2,000 pounds on wire.
15	.212	271	60,000	Annealed in coil 450° C.; 1 hour.
17	.216	271	60,000	Annealed in coil 600° C.; 1 hour; furnace cooled.
32	.223	373	37,500	800—$\frac{1}{2}$—10; air blast up; 2,000 pounds on wire.
41	.236	228	37,500	Wire from coil.
24	.266	373	37,500	800—$\frac{1}{2}$—10; air blast down; 1,200 pounds on wire.
4	.268	234	60,000	Wire from coil; not straightened.
54	.290	271	47,500	Annealed in coil 450° C.; 1 hour; furnace cooled.
10	.329	230	60,000	Wire from coil; not straightened.
46	.333	222	47,500	Do.
19	.334	373	60,000	800° C. in coil; cooled in air.
28	.362	373	37,500	800—$\frac{1}{2}$—10; air cooled; 2,000 pounds on wire.
49	.471	373	47,500	1,000—$\frac{1}{2}$—10; air blast up; 2,000 pounds on wire.
23	.474	271	60,000	800—2—30; air cooled; 2,000 pounds on wire.
30	.490	373	37,500	800—2—30; air blast; 2,000 pounds on wire.
26	.537	373	37,500	1,000—$\frac{1}{2}$—10; air blast up; 1,200 pounds on wire.
45a	.558	271	47,500	Wire from coil; not straightened.
2	.594	294	60,000	Do.
10a	.654	271	60,000	Do.

No. of test.	Ratio: Per cent set after cooling. / Per cent elongation produced by load.	Maximum temperature of heating (° C.).	Load (pounds).	Treatment.
40	0.762	271	37,500	Wire from coil; not straightened.
39	.822	300	37,500	Do.
11	.824	302	60,000	Do.
43	.845	300	47,500	Do.
16	.898	373	60,000	Annealed in coil 450° C. 1 hour; furnace cooled.
53	1.030	373	47,500	Do.
3	1.158	351	60,000	Wire from coil; not straightened.
21	1.182	271	60,000	800—2—30; air cooled; 1,200 pounds on wire.
14	1.225	373	60,000	Annealed in coil 450° C. 1 hour; furnace cooled.
12	1.376	350	60,000	Wire from coil; not straightened.
22	1.384	373	60,000	800—2—30; air cooled; 2,000 pounds on wire.
44	1.508	350	47,500	Wire from coil; not straightened.
42	1.723	373	47,500	Do.
38	1.777	351	37,500	Do.
18	2.040	373	60,000	800±25°, air cooled; heated by gas flame; 750 pounds on wire.
6	2.072	416	60,000	Wire from coil; not straightened.
37	2.200	373	37,500	Do.
13	2,723	373	60,000	Do.
1	3.91	416	60,000	Do.
9	3.947	448	60,000	Do.
48	4.03	373	47,500	800—½—10; air blast up; 1,200 pounds on wire.
20	4.170	373	60,000	800—2—30; air cooled; 1,200 pounds on wire.
47	4.57	395	47,500	800—½—10; air blast up; 1,200 pounds on wire.
5	7.22	455	60,000	Wire from coil; not straightened.
8	22.58	477	60,000	Do.

MICROSCOPICAL EXAMINATION.

The analysis of the one-eighth inch square gun wire was made and the results are as follows:

Chemical analysis.

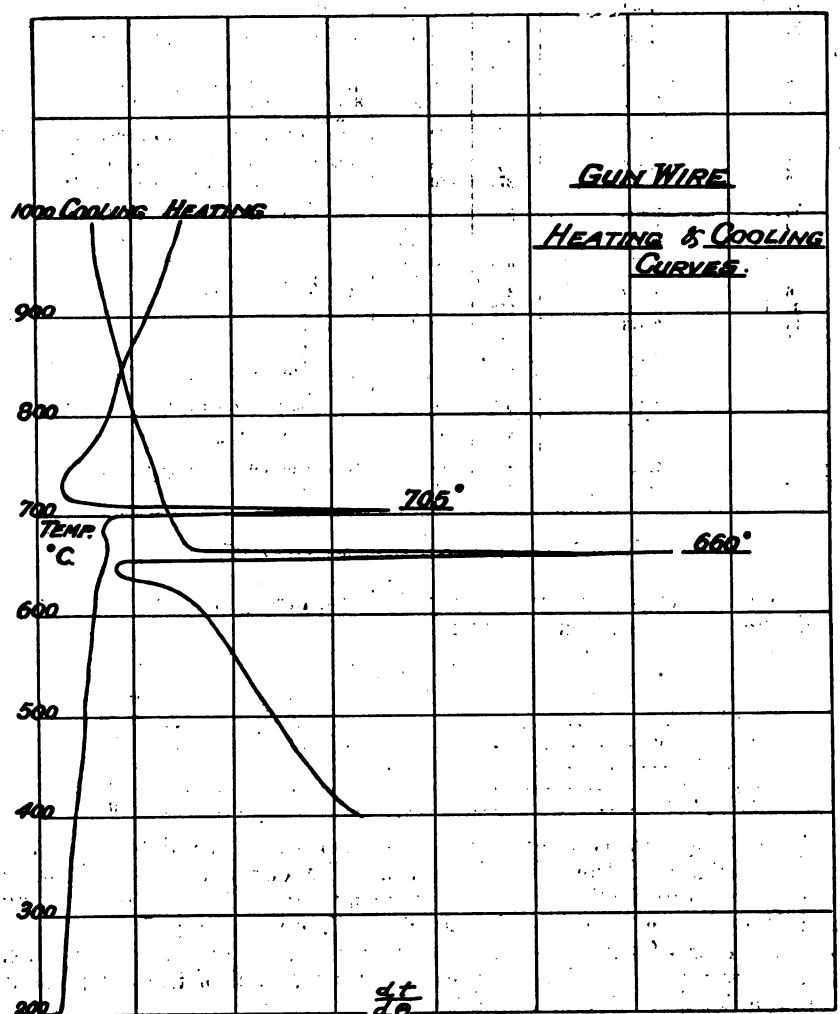
	Per cent.
Carbon	0.79
Manganese	.38
Silicon	.185
Sulphur	.043
Phosphorus	.036

A heating and cooling curve was also taken to determine the exact location of the critical points. The curve on the following page shows one well-marked point occurring at 705° C. on heating and the reverse of this point at 660° C. on cooling.

A number of micro-examinations were made on many sections, and a few representative samples are shown. All of these represent a magnification of 500 diameters.

The main features to be noted at present are, that in all specimens heated above the critical range, the distorted structure due to cold working has been removed.

The progressive change of structure brought about by annealing below the range is also of interest.


GUN WIRE
HEATING & COOLING CURVES.
1000
900
800
700
600
500
400
300
200
COOLING
HEATING
TEMP. °C.
705°
660°
dt/dθ

MICROGRAPH NO. 3686.

Wire annealed 1 hour at 600° C. The deformation due to drawing has been almost removed. A comparison with micrographs No. 3689 and No. 3688 will show the progressive removal of the cold-worked structure. The pearlite in this specimen was approaching the spherodized condition.

MICROGRAPH NO. 3687.

Heated to 800° C. and cooled in furnace. The elongation of constituents due to cold work has been completely removed. The structure is pearlitic intermingled with sorbite. The four micrographs Nos. 3688, 3689, 3686, 3687 show, first, the original structure; second, structure resulting by annealing 1 hour at 450° C., which is below the critical range; third, structure resulting by annealing 1 hour at 600° C., which is also below the critical range; and fourth, the structure resulting by annealing 1 hour above critical range followed by air cooling.

MICROGRAPH NO. 3688.

Heat treatment, as received from the manufacturer. It is very evident from this micrograph that any annealing to which the wire was subjected must have been carried out at a very low temperature. The elongation of the constituents due to drawing is very marked.

MICROGRAPH NO. 3689.

Wire annealed 1 hour at 450° C. The deformation due to drawing is still well defined. It was evident, however, that considerable readjustment of structure had taken place, and the decrease of tensile strength associated with the appearance of an elastic limit support this view.

MICROGRAPH NO. 3690.

800° C.±25°, cooled in air. Treated under tension of 750 pounds per square inch. Structure is very fine and no pearlite is present.

174-5

MICROGRAPH NO. 3691.

800° C.—2 inches—30 inches. 1,250 pounds per square inch on wire. Cooled in air. Poorly defined pearlite visible.

MICROGRAPH NO. 3692.

800° C.—2 inches—30 inches. 2,000 pounds per square inch on wire. Cooled in air. The structure is very similar to No. 3691, which differed only in having less weight on wire during treatment.

MICROGRAPH NO. 3695.

800—1/2 inch—10. 2,000 pounds per square inch on wire. Cooled in air. Structure is similar to 3687, which was heated to 800° C. in coil and cooled in air.

MICROGRAPH NO. 3696.

800° C.—1/2 inch—10 inches. 1,250 pounds per square nch on wire. Air blast directed upward. Traces of pearlite are apparent. Some of the higher transition constituents are undoubtedly present.

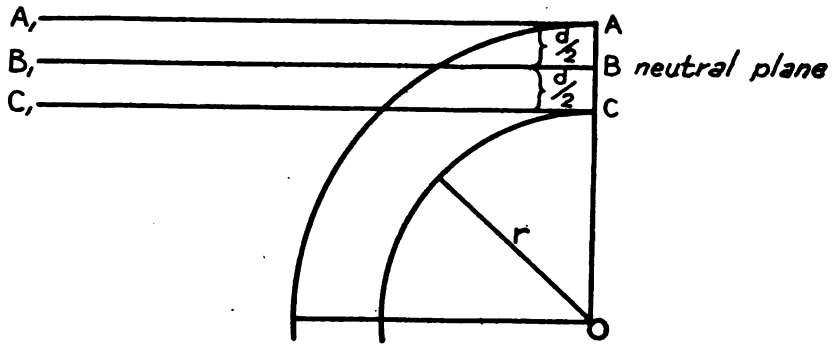
MICROGRAPH NO. 3697.

1000° C.—1/2 inch—10 inches. 1,250 pounds on wire. Air blast directed upward. Structure troosto-sorbitic. A small amount of excess ferrite visible.

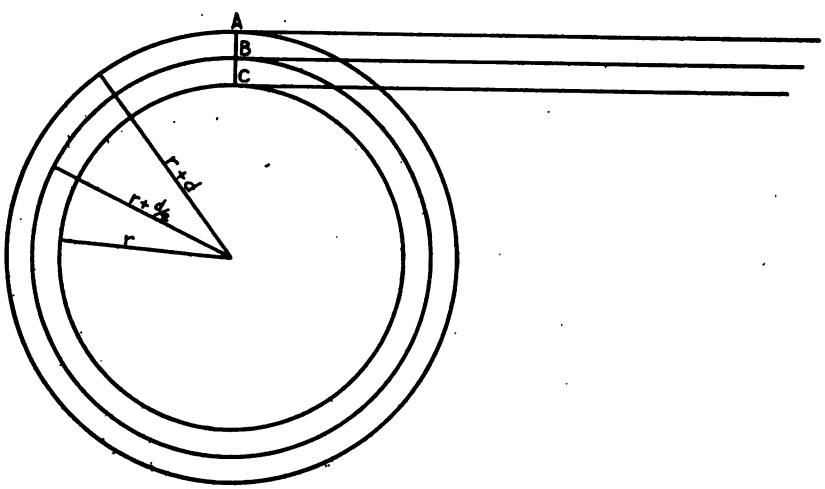
CALCULATIONS.

Let d = thickness of wire.
P = proportional limit of material comprising wire in tension.
P_1 = proportional limit of material comprising wire in compression.
M = modulus of elasticity of wire.
r = radius of coil on which wire is to be wound.

Assume neutral plane of wire on bending around coil to be located $\frac{d}{2}$ from inside and outside fibers.



If the free movement of inside fibers can not take place along circumference $2\pi r$ the neutral plane will be shifted toward CC_1. If all movement is prevented along circumference $2\pi r$, neutral plane will be CC_1. The most favorable condition would be to maintain neutral axis along BB_1. Therefore the following calculations are made on this assumption, and the result of the shifting of the neutral plane discussed later.



Assume wire so treated when straight that all fibers are free from strain.

Condition of above wire when wound on reel of radius r.

Consider first outside fibers:

Length of wire along neutral axis $= 2\pi\left(r+\frac{d}{2}\right)$

Length of wire along outside fibers $= 2\pi(r+d)$

Increase of length of outside fibers $= 2\pi(r+d) - 2\pi\left(r+\frac{d}{2}\right)$

$$\therefore \frac{2\pi(r+d) - 2\pi\left(r+\frac{d}{2}\right)}{2\pi\left(r+\frac{d}{2}\right)} M = \text{strain in outside fibers.}$$

$$\frac{d}{2r+d}\, M = \text{strain in outside fibers } (\textit{tension}).$$

In winding wire on reel or on gun tube, d is sufficiently small compared to 2r that $\frac{d}{2r+d}$ can be written $\frac{d}{2r}$

$$\frac{d}{2r} M = X = \text{strain in outside fibers.}$$

Considering inside fibers:

$$\frac{2\pi r - 2\pi\left(r+\frac{d}{2}\right)}{2\pi\left(r+\frac{d}{2}\right)} M = \text{strain in inside fibers.}$$

$$-\frac{d}{2r+d} M = \text{strain in inside fibers.}$$

$$-\frac{d}{2r} M = X_1 = \text{strain in inside fibers.}$$

For conditions of perfect elasticity on reel,

X must be equal to or less than P
X_1 must be equal to or less than P_1

For practical working conditions on reel,

$$X < P$$
and
$$X_1 < P_1$$

Example.

Gun wire $\frac{1}{8}$ inch square.
Treated when straight to obtain the following properties:

$$P = 80{,}000$$

$$P_1 = 80{,}000$$

$$M = 29{,}000{,}000$$

$$X = \frac{d}{2r}M$$

$$X = \left(\frac{.125}{2r}\right)(29{,}000{,}000)$$

Let $X = P$ which would allow no factor of safety.

$$80{,}000 = \left(\frac{.125}{2r}\right)(29{,}000{,}000)$$

$$16r = 362.5$$

$$r = 22.8''$$

In other words, to maintain wire perfectly elastic, allowing no factor of safety but working up to elastic limit, the minimum allowable radius of coil is 22.8 inches. If $\frac{1}{16}$-inch square gun wire was treated as above, minimum allowable radius = 18.1.

From these considerations it is evident that $\frac{1}{8}$-inch wire treated in straight condition could not be wound on a gun tube of less than 22.8 radius without passing the elastic limit of the outside and inside fibers.

DEVELOPMENT OF STRAINS IN EXTREME FIBERS WHEN WINDING UNDER TENSION.

ASSUMPTIONS.

Wire heated in straight condition as assumed previously to have proportional limit of P in tension, P_1 in compression, Modulus of M. d = thickness of wire and r_1 radius of gun tube.

From previous considerations it is evident that when wire is bent around tube, the outside fibers are under a strain of $\left(\frac{d}{2r_1}\right)(M)$ and the inside fibers $-\left(\frac{d}{2r_1}\right)(M)$.

Assume, then, that the winding machine is feeding wire to the tube under a tension of y, y being the tension necessary to produce the proper compression of the bore.

The strains, therefore, in the outside fibers of the wire would be $y + \left(\frac{d}{2r_1}\right)(M)$, and on the inside fibers $y - \left(\frac{d}{2r_1}\right)(M)$. Again

$$y + \left(\frac{d}{2r_1}\right)(M) < P$$

$$y - \left(\frac{d}{2r_1}\right)(M) < P_1$$

for perfectly elastic conditions.

EXAMPLE.

Ten-inch wire-wrapped B. L. rifle, 30 tons. (Notes on the Construction of Ordnance, No. 87.)

Outside radius of tube to receive wire forward of slip rings = 9.6 inches.

The proper constant tension for the wire in front of slip rings = 34,600 pounds.

One-tenth inch square wire, treated straight to 80,000 pounds elastic limit, Modulus 29,000,000.

OUTSIDE FIBERS OF WIRE.

$$y+\left(\frac{d}{2r_1}\right)(M)=X$$

$$34{,}000+\frac{.1}{2 \times 9.6}\ 29{,}000{,}000=X$$

$$X=185{,}600$$

As P = 80,000 the outside fibers are severely overstrained.

INSIDE FIBERS.

$$y-\left(\frac{d}{2r_1}\right)(M)=X$$

$$34{,}600-\frac{.1}{2 \times 9.6}\ 29{,}000{,}000=X$$

$$X=-116{,}400$$

$$P=-80{,}000.$$

Therefore inside fibers are severely overstrained.

All these conditions are with gun at rest.

Consideration of the term $y+\left(\frac{d}{2r}\right)(M)$ is of some interest. Y (winding tension) can be reduced by design to certain limits, but its value must not be decreased beyond a certain amount. The decrease in y could be accomplished, for example, by increasing the number of layers of wire. This could not be carried on indefinitely, as both weight and cost would be increased, and any possible advantages of a wire-wound construction over built-up construction would disappear.

The term $\left(\frac{d}{2r}\right)(M)$ can be varied and in a manner entirely compatible with practice. The value of M can be regarded as constant and closely approximating 29,000,000 pounds. r is fixed to rather narrow limits by design, namely, the bore of the gun and the thickness of the tube itself. Any possible increase of r, however, is of great advantage, as the fiber stresses produced by bending would vary inversely as r, and it would therefore be easier to construct an elastic wire-wound gun of large caliber than a wire-wound gun of low caliber.

The value of d is readily susceptible to variation, and it would appear that this could be done without seriously affecting the present

costs. The same effective cross section could be maintained, if desired, by using a wire of ribbon form. The wire in ribbon form would also possess an advantage in so far that it could, due to thinness of section, be much more readily heat-treated so as to obtain uniform properties throughout. A true elastic limit should then be prescribed and care taken that wire is received which does possess a true elastic limit.

To prevent the possibility of cold-worked wire being furnished, a clause could be introduced into the specifications stating that the last operation in the manufacture shall be a quench from above the critical range, followed by a tempering operation. The final tempering could be conducted 100° C. above any assembling or relining temperature, and in this way the department could be assured that any changes of physical properties or permanent sets due to assembling or relining heats would be avoided.

The following example is cited, to show in a concrete manner the advantages resulting from using a perfectly elastic ribbon wire. The wire used in this illustration could no doubt be obtained on a commercial scale at a very slight, if any, increase of cost over the present form used.

EXAMPLE.

10-inch wire-wrapped B. L. rifle, 30 tons.

Dimensions of wire: Thickness = .03 inch. Width = .33 inch.

Outside radius of tube to receive wire forward of slip rings = 9.6 inches.

The proper constant tension of winding = 34,600 pounds.

Wire treated straight to 120,000 pounds elastic limit. Modulus 29,000,000 pounds.

GUN AT REST—OUTSIDE FIBERS OF WIRE.

$$y+\left(\frac{d}{2r}\right)(M)=X$$

$$34{,}600+\frac{.03}{2 \times 9.6}\ 29{,}000{,}000=X$$

$$X=80{,}000 \text{ pounds approximately.}$$

This would leave a margin of 40,000 pounds for the stresses incidental to firing.

It is readily seen from the above that the change from .1 inch square wire to a .03 inch thick ribbon has reduced the outside fiber stress on the wire more than 105,000 pounds.

EXPERIMENT NO. 1.

[Final temperature, 416° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Sept. 26:							
9.15 a. m..	84	5,250	66.230	.....	.....	20	Room temperature.
10.00 a. m..	954	60,000	66.370	+0.140	0.140	20	Room temperature; current on.
10.35 a. m..	954	60,000	66.375	+ .005	.145	21	30° C.
11.10 a. m..	954	60,000	66.410	+ .035	.180	21	96° C.
11.35 a. m..	954	60,000	66.455	+ .045	.225	21	135° C.
12.00 m.....	954	60,000	66.520	+ .065	.290	21	210° C.
1.10 p. m..	954	60,000	66.725	+ .205	.495	21	340° C.
2.45 p. m..	954	60,000	67.175	+ .450	.945	21	416° C.; current off.
3.45 p. m..	954	60,000	67.000	− .175	.770	21	210° C.
4.40 p. m..	954	60,000	66.940	− .060	.710	21	112° C.
Sept. 27:							
9.00 a. m..	954	60,000	66.865	− .075	.635	20	Room temperature.
9.10 a. m..	84	5,250	66.735	− .130	.505	20	Do.

EXPERIMENT NO. 2.

[Final temperature, 294° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Sept. 27:							
3.10 p. m..	84	5,250	66.905	.....	.....	23	Room temperature.
3.35 p. m..	954	60,000	67.045	+0.140	0.140	23	Do.
5.00 p. m..	954	60,000	67.045	.....	.....	23	
Sept. 28:							
8.10 a. m..	954	60,000	67.055	+ .010	.150	20	
8.30 a. m.[1]	954	60,000	67.085	.....	.150	20	Current on.
9.00 a. m..	954	60,000	67.095	+ .010	.160	20	29° C.
9.20 a. m..	954	60,000	67.095	+ .000	.160	20	30° C.
9.40 a. m..	954	60,000	67.140	+ .045	.205	20	84° C.
10.05 a. m..	954	60,000	67.170	+ .030	.235	21	139° C.
10.50 a. m..	954	60,000	67.245	+ .075	.310	21	204° C.
11.10 a. m..	954	60,000	67.260	+ .015	.325	21	210° C.
12.05 p. m..	954	60,000	67.295	+ .035	.360	21	254° C.
1.05 p. m..	954	60,000	67.365	+ .070	.430	21	294° C.; current off.
2.15 p. m..	954	60,000	67.255	− .110	.320	21	133° C.
2.55 p. m..	954	60,000	67.225	− .030	.290	21	92° C.
3.35 p. m..	954	60,000	67.205	− .020	.270	21	60° C.
5.00 p. m..	954	60,000	67.185	− .020	.250	21	28° C.
Sept. 29:							
8.20 a. m..	954	60,000	67.165	− .020	.230	22	22° C.
8.45 a. m..	84	5,250	67.020	− .145	.085	.....	

[1] New gauge marks on wire. New length.

EXPERIMENT NO. 3.

[Final temperature, 351° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Sept. 29:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
11.30 a. m..	84	5,250	67.150	.....	.....	23	
11.55 a. m..	954	60,000	67.300	+0.150	0.150	24	
1.05 p. m..	954	60,000	67.300	+ .000	.150	24	
5.00 p. m..	954	60,000	67.300	+ .000	.150	24	
Sept. 30:							
8.10 a. m..	954	60,000	67.290	− .010	.140	19	
8.25 a. m.[1].	954	60,000	67.130	− .000	.140	19	Current on.
9.00 a. m..	954	60,000	67.145	+ .015	.155	20	24° C.
9.25 a. m..	954	60,000	67.155	+ .010	.165	20	34° C.
9.45 a. m..	954	60,000	67.175	+ .020	.185	21	73° C.
10.00 a. m..	954	60,000	67.215	+ .040	.225	21	114° C.
10.35 a. m..	954	60,000	67.250	+ .035	.260	21	164° C.
11.05 a. m..	954	60,000	67.285	+ .035	.295	21	204° C.
11.35 a. m..	954	60,000	67.310	+ .025	.320	21	225° C.
12.00 m.....	954	60,000	67.325	+ .015	.335	21	237° C.
1.05 p. m..	954	60,000	67.380	+ .055	.390	21	281° C.
1.20 p. m..	954	60,000	67.415	+ .035	.425	21	306° C.
1.30 p. m..	954	60,000	67.450	+ .035	.460	20	324° C.
1.35 p. m..	954	60,000	67.470	+ .020	.480	20	332° C.
1.50 p. m..	954	60,000	67.510	+ .040	.520	20	351° C.; current off.
2.05 p. m..	954	60,000	67.490	− .020	.500	20	304.
2.35 p. m..	954	60,000	67.435	− .055	.445	20	212.
3.05 p. m..	954	60,000	67.385	− .050	.395	20	149.
3.45 p. m..	954	60,000	67.345	− .040	.355	20	97.
5.00 p. m..	954	60,000	67.300	− .045	.310	20	42° C.
Oct. 2:							
9.30 a. m..	954	60,000	67.275	− .025	.285	19	Room temperature.
10.00 a. m..	84	5,250	67.115	− .160	.125	19	Do.

[1] Marks changed on wire.

EXPERIMENT NO. 4.

[Final temperature, 234° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Oct. 2:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
12.45 p. m..	84	5,250	67.360	.....	.....	20	Room temperature.
1.10 p. m..	954	60,000	67.500	+0.140	0.140	20	Do.
5.00 p. m..	954	60,000	67.505	+ .005	.145	20	Do.
Oct. 3:							
8.20 a. m.[1].	954	60,000	67.365	.000	.145	20	Room temperature; Current on.
8.25 a. m..	954	60,000	67.365	.000	.145	20	Room temperature.
9.40 a. m..	954	60,000	67.405	+ .040	.185	21	43° C.
10.15 a. m..	954	60,000	67.450	+ .045	.230	22	123° C.
10.35 a. m..	954	60,000	67.485	+ .035	.265	22	162° C.
10.55 a. m..	954	60,000	67.515	+ .030	.295	22	191° C.
11.10 a. m..	954	60,000	67.540	+ .025	.320	22	212° C.
11.40 a. m..	954	60,000	67.570	+ .030	.350	22	234° C.; current off.
1.00 p. m..	954	60,000	67.470	− .100	.250	21	92° C.
4.00 p. m..	954	60,000	67.420	− .050	.200	21	30° C.
5.00 p. m..	954	60,000	67.410	− .010	.190	21	Room temperature.
Oct. 4:							
8.25 a. m..	954	60,000	67.400	− .010	.180	18	Do.
9.10 a. m..	84	5,250	67.255	− .145	.035	18	Do.

[1] New marks on wire.

EXPERIMENT NO. 5.

[Final temperature, 455° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 5:							
8.25 a. m..	84	5,250	66.745	.....	.....	18	Room temperature.
9.00 a. m..	954	60,000	66.885	+0.140	0.140	18	Do.
9.25 a. m..	954	60,000	66.890	+ .005	.145	18	Do.
4.40 p. m..	954	60,000	66.885	− .005	.140	22	Do.
Oct. 6:							
9.15 a. m..	954	60,000	66.895	+ .010	.150	20	Room temperature; current on.
10.25 a. m..	954	60,000	66.925	+ .030	.180	20	47° C.
11.05 a. m..	954	60,000	66.990	+ .065	.245	21	137° C.
1.00 p. m..	954	60,000	67.090	+ .100	.345	21	237° C.
3.00 p. m..	954	60,000	67.150	+ .060	.405	21	274° C.
3.40 p. m..	954	60,000	67.265	+ .115	.520	22	346° C.
4.20 p. m..	954	60,000	67.390	+ .125	.645	22	378° C.
4.30 p. m..	954	60,000	67.465	+ .075	.720	22	410° C.
4.50 p. m..	954	60,000	67.920	+ .455	1.175	22	448° C.
4.55 p. m..	354	60,000	68.085	+ .165	1.340	22	455° C.
Oct. 7:							
8.00 a. m..	954	60,000	67.870	− .215	1.125	18	Room temperature.
8.20 a. m..	84	5,250	67.700	− .170	.955	18	Do.

EXPERIMENT NO. 6.

[Final temperature, 416° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 7:							
2.15 p. m..	84	5,250	66.590	.....	.....	21	Room temperature.
2.30 p. m..	954	60,000	66.740	+0.150	0.150	21	Do.
Oct. 8:							
8.30 a. m.[1].	954	60,000	66.755	+ .015	.165	21	Do.
10.15 a. m..	954	60,000	66.460	.....	.165	22	Do.
2.00 p. m..	954	60,000	66.455	− .005	.160	23	Do.
4.50 p. m..	954	60,000	66.455	.000	.160	23	Do.
Oct. 9:							
8.50 a. m..	954	60,000	66.460	.005	.165	20	Room temperature; current on.
9.05 a. m..	954	60,000	66.480	.020	.185	20	56° C.
9.25 a. m..	954	60,000	66.510	.030	.215	20	96° C.
9.35 a. m..	954	60,000	66.525	.015	.230	20	123° C.
10.20 a. m..	954	60,000	66.585	.060	.290	20	184° C.
11.20 a. m..	954	60,000	66.760	.175	.465	20	314° C.
11.35 a. m..	954	60,000	66.860	.100	.565	20	375° C.
11.40 a. m..	954	60,000	66.970	.110	.675	21	403° C.
11.45 a. m..	954	60,000	67.035	.065	.740	21	416° C.
1.20 p. m..	954	60,000	66.860	− .175	.565	21	136° C.
2.20 p. m..	954	60,000	66.810	− .050	.515	21	72° C.
8.55 p. m..	954	60,000	66.785	− .025	.490	21	
Oct. 10:							
8.20 a. m..	954	60,000	66.770	− .015	.475	20	Room temperature.
8.30 a. m..	954	60,000	66.605	− .165	.310	20	Do.

[1] Changed marks on wire.

EXPERIMENT NO. 8.

[Final temperature, 477° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 11:							
10.30 a. m..	84	5,250	66.400	.....	.....	23	
11.30 a. m..	954	60,000	66.540	+0.140	0.140	23	
4.00 p. m..	954	60,000	66.545	+ .005	.145	21	
Oct. 12:							
8.05 a. m..	954	60,000	66.545	+ .000	.145	18	Room temperature; current on.
8.30 a. m..	954	60,000	66.555	+ .010	.155	19	42° C.
9.00 a. m..	954	60,000	66.565	+ .010	.165	19	56° C.
9.25 a. m..	954	60,000	66.585	+ .020	.185	19	82° C.
9.45 a. m..	954	60,000	66.600	+ .015	.200	19	109° C.
10.05 a. m..	954	60,000	66.615	+ .015	.215	19	120° C.
11.30 a. m..	954	60,000	66.640	+ .025	.240	19	153° C.
11.50 a. m..	954	60,000	66.655	+ .015	.255	19	
12.10 p. m..	954	60,000	66.680	+ .025	.280	19	208° C.
12.20 p. m..	954	60,000	66.690	+ .010	.290	19	223° C.
12.45 p. m..	954	60.000	66.715	+ .025	.315	19	237° C.
1.10 p. m..	954	60,000	66.730	+ .015	.330	19	250° C.
1.20 p. m..	954	60,000	66.755	− .025	.355	19	283° C.
1.35 p. m..	954	60,000	66.810	+ .055	.410	19	315° C.
1.50 p. m..	954	60,000	66.875	+ .065	.475	19	348° C.
2.05 p. m..	954	60,000	66.920	+ .045	.520	19	365° C.
2.30 p. m..	954	60,000	66.975	+ .055	.575	19	375° C.
2.45 p. m..	954	60,000	67.000	+ .025	.600	19	383° C.
2.55 p. m..	954	60,000	67.030	+ .030	.630	19	395° C.
3.00 p. m..	954	60,000	67.060	+ .030	.660	19	406° C.
3.05 p. m..	954	60,000	67.100	+ .040	.700	19	417° C.
3.10 p. m..	954	60,000	67.145	+ .045	.745	19	427° C.
3.15 p. m..	954	60,000	67.200	+ .055	.800	19	438° C.
3.20 p. m..	954	60,000	67.280	+ .080	.880	19	448° C.
3.25 p. m..	954	60,000	67.415	+ .135	1.015	19	458° C.
3.30 p. m..	954	60,000	67.535	+ .120	1.135	19	462° C.
3.32 p. m..	954	60,000	67.655	+ .120	1.255	19	465° C.
3.35 p. m..	954	60,000	67.815	+ .160	1.415	19	466° C.
3.40 p. m..	954	60,000	67.925	+ .110	1.525	19	466° C.
3.45 p. m..	954	60,000	68.090	+ .165	1.690	19	468° C.
3.50 p. m..	954	60,000	68.420	+ .330	2.020	19	468° C.
4.00 p. m..	954	60,000	68.785	+ .365	2.385	19	472° C.
4.02 p. m..	954	60,000	68.995	+ .210	2.595	19	477° C.
4.05 p. m..	954	60,000	69.150	+ .155	2.750	19	477° C.
4.08 p. m..	954	60,000	69.410	+ .260	3.010	19	477° C.
Oct. 13:							
2.05 p. m..	954	60,000	69.505	+ .095	3.105	20	
3.15 p. m..	954	60,000	69.500	− .005	3.100	20	
3.30 p. m..	84	5,250	69.335	− .165	2.935	20	

EXPERIMENT NO. 9.

[Final temperature, 448° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 13:							
4.30 p. m..	84	5,250	66.360	.....	.....	20	Room temperature.
5.00 p. m..	954	60,000	66.515	+0.155	0.155	20	Do.
Oct. 14:							
1.55 p. m..	954	60,000	66.515	+ .000	.155	23	23° C.; 3 ampere.
2.15 p. m..	954	60,000	66.615	+ .100	.255	23	159° C.
2.25 p. m..	954	60,000	66.640	+ .025	.280	23	193° C.
2.30 p. m..	954	60,000	66.690	+ .050	.330	23	238° C.
2.40 p. m..	954	60,000	66.725	+ .035	.365	23	272° C.
2.45 p. m..	954	60,000	66.755	+ .030	.395	23	285° C.
2.48 p. m..	954	60,000	66.770	+ .015	.410	23	299° C.
2.50 p. m..	954	60,000	66.800	+ .030	.440	23	319° C.
2.55 p. m..	954	60,000	66.830	+ .030	.470	23	332° C.
2.57 p. m..	954	60,000	66.855	+ .025	.495	23	350° C.
3.00 p. m..	954	60,000	66.890	+ .035	.530	23	364° C.
3.05 p. m..	954	60,000	66.940	+ .050	.580	23	383° C.
3.08 p. m..	954	60,000	66.990	+ .050	.630	23	395° C.
3.11 p. m..	954	60,000	67.015	+ .025	.655	23	405° C.
3.14 p. m..	954	60,000	67.070	+ .055	.710	23	417° C.
3.18 p. m..	954	60,000	67.125	+ .055	.765	23	426° C.
3.20 p. m..	954	60,000	67.175	+ .050	.815	22	436° C.
3.25 p. m..	954	60,000	67.300	+ .125	.940	22	448° C.; current off.
3.30 p. m..	954	60,000	67.340	+ .040	.980	22	Falling temperature by couple.
4.30 p. m..	954	60,000	67.165	− .175	.805	21	212° C.
Oct. 16:							
8.00 a. m..	954	60,000	67.050	− .115	.690	19	Room temperature.
8.30 a..m..	84	5,250	66.870	− .180	.510	19	Do.

EXPERIMENT NO. 10.

[Final temperature, 230° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 16:							
11.00 a. m..	84	5,250	67.130	.....	.....	18	Room temperature.
11.15 a. m..	954	60,000	67.280	+0.150	+0.150	19	Do.
4.45 p. m..	954	60,000	67.280	+ .000	+ .150	18	Do.
Oct. 17:							
8.00 a. m..	954	60,000	67.280	+ .000	+ .150	17	Do.
8.10 a. m.[1].	954	60,000	67.060	+ .000	+ .150	17	Room temperature; current on.
8.25 a. m..	954	60,000	67.140	+ .080	+ .230	17	129° C.
8.40 a. m..	954	60,000	67.230	+ .090	.320	18	232° C.
8.45 a. m..	954	60,000	67.245	+ .015	.335	18	227° C.
8.55 a. m..	954	60,000	67.240	− .005	.330	18	225° C.
9.10 a. m..	954	60,000	67.250	+ .010	.340	18	227° C.
9.25 a. m..	954	60,000	67.250	+ .000	.340	19	230° C.
9.55 a. m..	954	60,000	67.250	+ .000	.340	19	230° C.
10.35 a. m..	954	60,000	67.250	+ .000	.340	19	230° C.
11.15 a. m..	954	60,000	67.250	+ .000	.340	19	230° C.
11.50 a. m..	954	60,000	67.255	.005	.345	19	230° C.
1.10 p. m..	954	60,000	67.255	.000	.345	20	230° C.
2.40 p. m..	954	60,000	67.260	.005	.350	20	230° C.; current off.
4.25 p. m..	954	60,000	67.150	− .110	.240	20	82° C.
5.00 p. m..	954	60,000	67.135	− .015	.225	20	64° C.
Oct. 18:							
8.00 a. m..	954	60,000	67.105	− .030	.195	18	Room temperature.
9.00 a. m..	84	5,250	66.970	− .135	.060	18	Do.

[1] Changed marks on wire.

EXPERIMENT NO. 10A.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Oct. 18:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
1.30 p. m..	84	5,250	66.665	.....	.....	22	
2.00 p. m..	954	60,000	66.820	+0.155	0.155	22	
4.05 p. m..	954	60,000	66.820	+ .000	.155	21	
4.30 p. m..	954	60,000	66.810	− .010	.145	21	
Oct. 19:							
8.30 a. m..	954	60,000	66.810	+ .000	.145	19	Room temperature; current on.
8.50 a. m..	954	60,000	66.930	+ .120	.265	19	183° C.
8.55 a. m..	954	60,000	66.950	+ .020	.285	19	202° C.
9.00 a. m..	954	60,000	66.975	+ .025	.310	20	225° C.
9.07 a. m..	954	60,000	67.015	+ .040	.350	20	268° C.
9.15 a. m..	954	60,000	67.035	+ .020	.370	20	271° C.
9.25 a. m..	954	60,000	67.035	+ .000	.370	20	269° C.
9.40 a. m..	954	60,000	67.040	+ .005	.375	21	271° C.
9.50 a. m..	954	60,000	67.050	+ .010	.385	21	271° C.
10.10 a. m..	954	60,000	67.045	− .005	.380	21	271° C.
10.40 a. m..	954	60,000	67.050	+ .005	.385	21	271° C.
11.05 a. m..	954	60,000	67.055	+ .005	.390	21	271° C.
11.40 a. m..	954	60,000	67.055	+ .000	.390	21	271° C.
1.00 p. m..	954	60,000	67.070	+ .015	.405	22	272° C.
3.10 p. m..	954	60,000	67.075	+ .005	.410	22	271° C.
3.15 p. m..	954	60,000	67.080	+ .005	.415	22	271° C.
4.50 p. m..	954	60,000	66.965	− .115	.300	22	112° C.
Oct. 20:							
8.00 a. m..	954	60,000	66.895	− .070	.230	20	Room temperature.
8.30 a. m..	84	5,250	66.760	− .135	.095	20	

EXPERIMENT NO. 11.

[Final temperature, 304° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Oct. 24:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
2.15 p. m..	84	5,250	67.640	.....	.....	21	
3.25 p. m..	954	60,000	67.795	+0.155	0.155	21	
4.25 p. m..	954	60,000	67.800	− .005	.160	21	
4.30 p. m..	954	60,000	67.805	+ .005	.165	21	
4.45 p. m..	954	60,000	67.800	− .005	.160	21	
4.55 p. m..	954	60,000	67.795	− .005	.155	21	
Oct. 25:							
8.00 a. m..	954	60,000	67.795	0.000	.155	17	
8.30 a. m.[1].	954	60,000	66.795	0.	.155	21	Room temperature; current on.
8.50 a. m..	954	60,000	66.870	+ .075	.230	21	148° C.
8.55 a. m..	954	60,000	66.910	+ .040	.270	21	138° C.
9.00 a. m..	954	60,000	66.950	+ .040	.310	21	238° C.
9.08 a. m..	954	60,000	66.990	+ .040	.350	21	264° C.
9.15 a. m..	954	60,000	67.020	+ .030	.380	21	289° C.
9.16 a. m..	954	60,000	67.030	+ .010	.390	21	294° C.
9.30 a. m..	954	60,000	67.055	+ .025	.415	21	302° C.
9.40 a. m..	954	60,000	67.065	+ .010	.425	21	302° C.
10.10 a. m..	954	60,000	67.070	+ .005	.430	21	302° C.
10.15 a. m..	954	60,000	67.075	+ .005	.435	21	304° C.
10.35 a. m..	954	60,000	67.065	− .010	.425	21	304° C.
10.50 a. m..	954	60,000	67.070	+ .005	.430	21	304° C.
11.50 a. m..	954	60,000	67.075	+ .005	.435	21	301° C.
12.00 m.....	954	60,000	67.080	+ .005	.440	21	301° C.
12.55 p. m..	954	60,000	67.090	+ .010	.450	21	303° C.
1.30 p. m..	954	60,000	67.090	0.000	.450	23	301° C.
1.45 p. m..	954	60,000	67.100	+ .010	.460	23	303° C.
2.20 p. m..	954	60,000	67.100	0.000	.460	23	303° C.
2.50 p. m..	954	60,000	67.105	+ .005	.465	23	302° C.
3.10 p. m..	954	60,000	67.100	− .005	.460	23	302° C.
3.30 p. m..	954	60,000	67.100	0.000	.460	21	302° C.; current off.
3.40 p. m..	954	60,000	67.070	− .030	.430	21	269° C.
3.50 p. m..	954	60,000	67.050	− .020	.410	21	247° C.
4.35 p. m..	954	60,000	66.995	− .055	.355	21	154° C.
8.25 p. m..	954	60,000	66.910	− .085	.270	21	Room temperature.
8.35 p. m..	954	60,000	66.770	− .140	.130	.....	

[1] New marks on wire.

EXPERIMENT NO. 12.

[Final temperature, 351° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 26:							
10.30 a. m..	84	5,250	68.205	.....	.....	.....	
11.30 a. m..	954	60,000	68.365	+0.160	0.160	.....	
4.00 p. m..	954	60,000	68.365	0.000	.160	21	
Oct. 27:							
7.55 a. m..	954	60,000	68.370	+ .005	.165	22	Room temperature; current on.
8.25 a. m..	954	60,000	68.570	+ .200	.365	22	271° C.
8.35 a. m..	954	60,000	68.630	+ .060	.425	22	320° C.
8.45 a. m..	954	60,000	68.690	+ .060	.485	22	350° C.
8.52 a. m..	954	60,000	68.705	+ .015	.500	22	350° C.
9.10 a. m..	954	60,000	68.725	+ .020	.520	22	350° C.
9.30 a. m..	954	60,000	68.745	+ .020	.540	22	351° C.
9.45 a. m..	954	60,000	68.765	+ .020	.560	22	351° C.
10.00 a. m..	954	60,000	68.770	+ .005	.565	22	351° C.
10.30 a. m..	954	60,000	68.775	+ .005	.570	22	351° C.
10.55 a. m..	954	60,000	68.790	+ .015	.585	22	351° C.
11.30 a. m..	954	60,000	68.795	+ .005	.590	22	350° C.
11.50 a. m..	954	60,000	68.800	+ .005	.595	22	350° C.
1.10 p. m..	954	60,000	68.810	+ .010	.605	22	351° C.
2.05 p. m..	954	60,000	68.810	0.000	.605	22	349° C.
2.55 p. m..	954	60,000	68.810	0.000	.605	22	351° C.; current off.
3.20 p. m..	954	60,000	68.760	− .050	.555	22	267° C.
4.00 p. m..	954	60,000	68.680	− .080	.475	22	189° C.
4.35 p. m..	954	60,000	68.640	− .040	.435	22	129° C.
Oct. 28:							
8.10 a. m..	954	60,000	68.570	− .070	.365	22	Room temperature.
8.35 a. m..	84	5,250	68.440	− .130	.235	22	

EXPERIMENT NO. 13.

[Final temperature, 377° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Oct. 28:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
3.10 p. m..	84	5,250	67.815	.....	.....	23	
3.30 p. m..	954	60,000	67.960	+0.145	0.145	23	
4.00 p. m..	954	60,000	67.965	+ .005	.150	23	
4.50 p. m..	954	60,000	67.955	− .010	.140	23	
Oct. 30:							
8.20 a. m..	954	60,000	67.950	− .005	.135	18	Current on.
8.30 a. m..	954	60,000	67.980	+ .030	.165	18	69° C.
8.35 a. m..	954	60,000	68.015	+ .035	.200	18	122° C.
8.40 a. m..	954	60,000	68.045	+ .030	.230	18	149° C.
8.44 a. m..	954	60,000	68.085	+ .040	.270	18	186° C.
8.49 a. m..	954	60,000	68.100	+ .015	.285	18	210° C.
8.55 a. m..	954	60,000	68.160	+ .060	.345	18	259° C.
9.05 a. m..	954	60,000	68.220	+ .060	.405	18	305° C.
9.14 a. m..	954	60,000	68.280	+ .060	.465	18	339° C.
9.21 a. m..	954	60,000	68.345	+ .065	.530	18	373° C.
9.31 a. m..	954	60,000	68.385	+ .040	.570	18	373° C.
9.49 a. m..	954	60,000	68.400	+ .015	.585	18	373° C.
10.03 a. m..	954	60,000	68.420	+ .020	.605	18	373° C.
10.20 a. m..	954	60,000	68.430	+ .010	.615	18	373° C.
10.35 a. m..	954	60,000	68.440	+ .010	.625	18	373° C.
11.00 a. m..	954	60,000	68.455	+ .015	.640	18	373° C.
11.30 a. m..	954	60,000	68.465	+ .010	.650	18	373° C.
12.00 m.....	954	60,000	68.460	− .005	.645	18	373° C.
12.30 p. m..	954	60,000	68.490	+ .030	.675	18	377° C.
1.00 p. m..	954	60,000	68.490	0.000	.675	18	373° C.
1.30 p. m..	954	60,000	68.490	0.000	.675	18	373° C.
2.00 p. m..	954	60,000	68.495	+ .005	.680	18	373° C.
2.30 p. m..	954	60,000	68.505	− .010	.690	18	373° C.
3.00 p. m..	954	60,000	68.510	+ .005	.695	18	373° C.
3.21 p. m..	954	60,000	68.510	0.000	.695	18	373° C.; current off.
3.30 p. m..	954	60,000	68.470	− .040	.655	18	328° C.
3.35 p. m..	954	60,000	68.440	− .030	.625	18	294° C.
3.53 p. m..	954	60,000	68.420	− .020	.605	18	261° C.
4.10 p. m..	954	60,000	68.395	− .025	.580	18	222° C.
4.33 p. m..	954	60,000	68.365	− .030	.580	18	173° C.
4.58 p. m..	954	60,000	68.340	− .025	.525	18	135° C.
Oct. 31:							
8.10 a. m..	954	60,000	68.275	− .065	.460	21	Room temperature.
8.44 a. m..	84	5,250	68.105	− .170	.290	21	Do.

EXPERIMENT NO. 14.

[Final temperature, 374° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Oct. 31:							
11.40 a. m..	84	5,250	66.595	.....	.....	.....	
1.10 p. m..	84	5,250	66.595	.....	.....	.....	
1.30 p. m..	954	60,000	66.760	+0.165	0.165	.....	
2.00 p. m..	954	60,000	66.740	− .020	.145	.....	
3.30 p. m..	954	60,000	66.750	+ .010	.155	22	
4.30 p. m..	954	60,000	66.750	0.000	.155	22	
Nov. 1:							
8.20 a. m..	954	60,000	66.740	− .010	.145	19	Current on; room temperature.
8.25 a. m..	954	60,000	66.760	+ .020	.165	19	69° C.
8.29 a. m..	954	60,000	66.795	+ .035	.200	19	109° C.
8.32 a. m..	954	60,000	66.810	+ .015	.215	19	135° C.
8.37 a. m..	954	60,000	66.845	+ .035	.250	19	173° C.
8.43 a. m..	954	60,000	66.875	+ .030	.280	19	210° C.
8.51 a. m..	954	60,000	66.925	+ .050	.330	19	259° C.
8.59 a. m..	954	60,000	66.960	+ .035	.365	19	294° C.
9.07 a. m..	954	60,000	66.995	+ .035	.400	19	328° C.
9.21 a. m..	954	60,000	67.055	+ .060	.460	19	373° C.
9.31 a. m..	954	60,000	67.075	+ .020	.480	19	373° C.
9.45 a. m..	954	60,000	67.080	+ .005	.485	19	373° C.
10.00 a. m..	954	60,000	67.080	0.000	.485	19	373° C.
10.30 a. m..	954	60,000	67.100	+ .020	.505	19	373° C.
11.00 a. m..	954	60,000	67.100	0.000	.505	19	373° C.
11.30 a. m..	954	60,000	67.110	+ .010	.515	19	373° C.
12.00 m.....	954	60,000	67.115	+ .005	.520	19	373° C.
12.30 p. m..	954	60,000	67.115	0.000	.520	19	373° C.
1.00 p. m..	954	60,000	67.120	+ .005	.525	22	373° C.
1.30 p. m..	954	60,000	67.125	+ .005	.530	22	373° C.
2.00 p. m..	954	60,000	67.125	0.000	.530	22	373° C. Went to 374° C. at 2.15 p. m.
2.30 p. m..	954	60,000	67.135	+ .010	.540	22	373° C.
3.00 p. m..	954	60,000	67.135	0.000	.540	22	373° C.
3.21 p. m..	954	60,000	67.140	+ .005	.545	22	373° C.; current off.
3.34 p. m..	954	60,000	67.105	− .035	.510	22	328° C.
3.43 p. m..	954	60,000	67.075	− .030	.480	22	294° C.
3.55 p. m..	954	60,000	67.050	− .025	.455	22	259° C.
4.11 p. m..	954	60,000	67.020	− .030	.425	22	222° C.
4.29 p. m..	954	60,000	67.000	− .020	.405	22	186° C.
5.00 p. m..	954	60,000	66.960	− .040	.365	22	135° C.
Nov. 2:							
8.05 a. m..	954	60,000	66.900	− .060	.305	21	Room temperature.
8.54 a. m..	84	5,250	66.755	−. 145	.160	21	Do.

EXPERIMENT NO. 15.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 2:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
11.30 a. m..	84	5,250	68.085	.....	.....	20	
1.10 p. m..	954	60,000	68.230	+0.145	0.145	20	
4.30 p. m..	954	60,000	68.230	0.000	.145	20	
Nov. 3:							
8.07 a. m..	954	60,000	68.245	+ .015	.160	20	
			New marks on wire.				
8.15 a. m..	954	60,000	68.025	0.000	.160	22	Current on.
8.25 a. m..	954	60,000	68.070	+ .045	.205	22	96° C.
8.30 a. m..	954	60,000	68.110	+ .040	.245	22	152° C.
8.34 a. m..	954	60,000	68.145	+ .035	.280	22	186° C.
8.38 a. m..	954	60,000	68.175	+ .030	.310	22	222° C.
8.45 a. m..	954	60,000	68.210	+ .035	.345	22	259° C.
8.46 a. m..	954	60,000	68.220	+ .010	.355	22	271° C.
9.06 a. m..	954	60,000	68.225	+ .005	.360	22	271° C.
9.30 a. m..	954	60,000	68.225	0.000	.360	22	271° C.
10.00 a. m..	954	60,000	68.220	− .005	.355	22	271° C.
10.30 a. m..	954	60,000	68.220	0.000	.355	22	271° C.
11.00 a. m..	954	60,000	68.230	+ .010	.365	22	271° C.
11.30 a. m..	954	60,000	68.230	0.000	.365	22	271° C.
12.00 m....	954	60,000	68.235	+ .005	.370	22	271° C.
12.30 p. m..	954	60,000	68.230	− .005	.365	22	271° C.
1.00 p. m..	954	60,000	68.230	0.000	.365	22	271° C.
1.30 p. m..	954	60,000	68.230	0.000	.365	22	271° C.
2.00 p. m..	954	60,000	68.230	0.000	.365	22	271° C.
2.30 p. m..	954	60,000	68.225	− .005	.360	22	271° C.
2.46 p. m..	954	60,000	68.230	+ .005	.365	22	Current off; 271° C.
2.50 p. m..	954	60,000	68.220	− .010	.355	22	259° C.
3.04 p. m..	954	60,000	68.195	− .025	.330	22	222° C.
3.22 p. m..	954	60,000	68.175	− .020	.310	22	186° C.
3.53 p. m..	954	60,000	68.135	− .040	.270	22	135° C.
4.32 p. m..	954	60,000	68.105	− .030	.240	23	96° C.
Nov. 4:							
8.06 a. m..	954	60,000	68.055	− .050	.190	22	Room temperature.
8.27 a. m..	84	5,250	67.930	− .125	.065	22	Do.

EXPERIMENT NO. 16.

[Final temperature, 374° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Nov. 4:							
11.05 a. m..	84	5,250	68.180			22	Room temperature.
11.30 a. m..	954	60,000	68.350	+0.170	0.170	22	Do.
1.25 p. m..	84	5,250	68.225	− .125	.045	22	Do.
1.50 p. m..	954	60,000	68.360	+ .135	.180	22	Do.
3.30 p. m..	954	60,000	68.360	0.000	.180	24	Do.
3.50 p. m..	84	5,250	68.220	− .140	.040	24	
4.00 p. m..	954	60,000	68.365	+ .145	.185	24	
4.35 p. m..	954	60,000	68.365	0.000	.185	24	
Nov. 6:							
8.05 a. m..	954	60,000	68.365	0.000	.185	15	Current on.
8.16 a. m..	954	60,000	68.415	+ .050	.235	15	96° C.
8.21 a. m..	954	60,000	68.435	+ .020	.255	18	135° C.
8.29 a. m..	954	60,000	68.475	+ .040	.295	17	186° C.
8.34 a. m..	954	60,000	68.505	+ .030	.325	17	222° C.
8.40 a. m..	954	60,000	68.550	+ .045	.370	18	258° C.
8.46 a. m..	954	60,000	68.580	+ .030	.400	18	294° C.
8.53 a. m..	954	60,000	68.615	+ .035	.435	18	328° C.
9.03 a. m..	954	60,000	68.680	+ .065	.500	18	373° C.
9.12 a. m..	954	60,000	68.690	+ .010	.510	18	373° C.
9.30 a. m..	954	60,000	68.695	+ .005	.515	18	373° C.
10.00 a. m..	954	60,000	68.700	+ .005	.520	20	373° C.
10.30 a. m..	954	60,000	68.710	+ .010	.530	20	373° C.
11.00 a. m..	954	60,000	68.715	+ .005	.535	22	373° C.
11.30 a. m..	954	60,000	68.720	+ .005	.540	22	373° C.
12.00 m ..	954	60,000	68.725	+ .005	.545	22	374° C.
12.30 p. m..	954	60,000	68.735	+ .010	.555	22	373° C.
1.00 p. m..	954	60,000	68.745	+ .010	.565	22	373° C.
1.30 p. m..	954	60,000	68.745	0.000	.565	22	373° C.
2.00 p. m..	954	60,000	68.755	+ .010	.575	22	373° C.
2.30 p. m..	954	60,000	68.750	− .005	.570	22	373° C.
3.03 p. m..	954	60,000	68.750	0.000	.570	22	373° C.; current off.
3.12 p. m..	954	60,000	68.720	− .030	.540	22	328° C.
3.25 p. m..	954	60,000	68.695	− .025	.515	22	294° C.
3.37 p. m..	954	60,000	68.665	− .030	.485	22	259° C.
3.51 p. m..	954	60,000	68.645	− .020	.465	22	223° C.
4.10 p. m..	954	60,000	68.605	− .040	.425	22	186° C.
4.40 p. m..	954	60,000	68.570	− .035	.390	22	135° C.
Nov. 7:							
8.02 a. m..	954	60,000	68.510	− .060	.330	20	Room temperature.
8.28 a. m..	84	5,250	68.375	− .135	.195	20	Do.

EXPERIMENT NO. 17.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 7:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
10.49 a. m..	84	5,250	68.820	.....	.....	22	Room temperature.
11.19 a. m..	954	60,000	68.990	+0.170	0.170	22	Do.
1.00 p. m..	954	60,000	69.005	+ .015	.185	23	Do.
1.12 p. m..	84	5,250	68.860	− .145	.040	23	Do.
1.35 p. m..	954	60,000	69.005	+ .145	.185	23	Do.
Nov. 8:							
8.06 a. m..	954	60,000	69.005	0.000	.185	17	Room temperature; current on.
8.17 a. m..	954	60,000	69.050	+ .045	.230	17	96° C.
8.22 a. m..	954	60,000	69.080	+ .030	.260	17	135° C.
8.29 a. m..	954	60,000	69.130	+ .050	.310	17	186° C.
8.35 a. m..	954	60,000	69.160	+ .030	.340	17	222° C.
8.40 a. m..	954	60,000	69.195	+ .035	.375	17	259° C.
8.49 a. m..	954	60,000	69.205	+ .010	.385	17	271° C.
9.00 a. m..	954	60,000	69.210	+ .005	.390	17	271° C.
9.30 a. m..	954	60,000	69.210	0.000	.390	21	271° C.
10.00 a. m..	954	60,000	69.210	0.000	.390	21	271° C.
10.30 a. m..	954	60,000	69.210	0.000	.390	21	271° C.
11.00 a. m..	954	60,000	69.210	0.000	.390	21	271° C.
11.30 a. m..	954	60,000	69.210	0.000	.390	21	271° C.
12.00 m.....	954	60,000	69.210	0.000	.390	21	271° C.
1.00 p. m..	954	60,000	69.210	0.000	.390	21	271° C.
1.30 p. m..	954	60,000	69.210	0.000	.390	21	271° C.
2.15 p. m..	954	60,000	69.210	0.000	.390	21	271° C.
2.49 p. m..	954	60,000	69.210	0.000	.390	21	271° C.
3.15 p. m..	954	60,000	69.170	− .040	.350	21	213° C.
Nov. 9:							
8.03 a. m..	954	60,000	69.040	− .130	.220	21	Room temperature.
8.20 a. m..	84	5,250	68.910	− .130	.090	21	Do.

EXPERIMENT NO. 18.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 8:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
11.40 a. m..	84	5,250	67.955	.....	.....	.....	
12.01 p. m..	954	60,000	68.085	+0.130	0.130	.....	
			New marks.				
1.00 p. m..	954	60,000	67.990	0.000	.130	.....	
Nov. 9:							
8.10 a. m..	954	60,000	67.990	0.000	.130	20	Room temperature.
			New marks.				
8.30 a. m..	954	60,000	67.710	0.000	.130	20	Room temperature; current on.
8.38 a. m..	954	60,000	67.760	+ .050	.180	20	96° C.
8.43 a. m..	954	60,000	67.795	+ .035	.215	20	136° C.
8.49 a. m..	954	60,000	67.855	+ .060	.275	20	186° C.
8.55 a. m..	954	60,000	67.905	+ .050	.325	20	222° C.
9.00 a. m..	954	60,000	67.945	+ .040	.365	20	259° C.
9.07 a. m..	954	60,000	68.005	+ .060	.425	20	305° C.
9.14 a. m..	954	60,000	68.065	+ .060	.485	20	339° C.
9.21 a. m..	954	60,000	68.115	+ .050	.535	20	373° C.
9.31 a. m..	954	60,000	68.135	+ .020	.555	20	373° C.
10.00 a. m..	954	60,000	68.150	+ .015	.570	20	373° C.
10.30 a. m..	954	60,000	68.160	+ .010	.580	20	373° C.
11.00 a. m..	954	60,000	68.170	+ .010	.590	20	373° C.
11.30 a. m..	954	60,000	68.180	+ .010	.600	20	373° C.
12.00 m.....	954	60,000	68.175	− .005	.595	20	373° C.
12.30 p. m..	954	60,000	68.180	+ .005	.600	20	373° C.
1.00 p. m..	954	60,000	68.185	+ .005	.605	20	373° C.
1.30 p. m..	954	60,000	68.190	+ .005	.610	20	373° C.
2.00 p. m..	954	60,000	68.190	0.000	.610	22	373° C.
2.30 p. m..	954	60,000	68.190	0.000	.610	22	373° C.
3.00 p. m..	954	60,000	68.195	+ .005	.615	22	373° C.
3.24 p. m..	954	60,000	68.195	0.000	.615	22	373° C.; current off.
3.35 p. m..	954	60,000	68.170	− .025	.590	22	339° C.
3.43 p. m..	954	60,000	68.145	− .025	.565	22	305° C.
3.59 p. m..	954	60,000	68.105	− .040	.525	22	259° C.
4.58 p. m..	954	60,000	68.025	− .080	.445	22	
Nov. 11:							
8.03 a. m..	954	60,000	67.945	− .080	.365	20	Room temperature.
8.17 a. m..	84	5,250	67.825	− .120	.245	20	Do.

EXPERIMENT NO. 19.

[Final temperature, 333° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 11:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.14 a. m..	84	5,250	67.585	.....	.....	20	Room temperature.
9.30 a. m..	954	60,000	68.305	+ .720	0.720	20	Current on; room temperature.
9.43 a. m..	954	60,000	68.370	+ .065	.785	20	96[b] C.
9.47 a. m..	954	60,000	68.405	+ .035	.820	20	136° C.
9.54 a. m..	954	60,000	68.455	+ .050	.870	20	186° C.
9.59 a. m..	954	60,000	68.485	+ .030	900	20	222° C.
10.04 a. m..	954	60,000	68.510	+ .025	.925	20	259° C.
10.13 a. m..	954	60,000	68.550	+ .040	.965	20	305° C.
10.19 a. m..	954	60,000	68.590	+ .040	1.005	20	339° C.
10.30 a. m..	954	60,000	68.670	+ .080	1.085	20	373° C.
10.45 a. m..	954	60,000	68.695	+ .025	1.110	20	373° C.
11.00 a. m..	954	60,000	68.720	+ .025	1.135	20	373° C.
11.30 a. m..	954	60,000	68.725.	+ .005	1.140	20	373° C.
12.00 m.....	954	60,000	68.735	+ .010	1.150	20	373° C.
12.30 p. m..	954	60,000	68.755	+ .020	1.170	20	383° C.
1.00 p. m..	954	60,000	68.755	0.000	1.170	20	373° C.
1.30 p. m..	954	60,000	68.765	+ .010	1.180	20	373° C.
2.00 p. m..	954	60,000	68.760	− .005	1.175	20	373° C.
2.30 p. m..	954	60,000	68.760	0.000	1.175	20	373° C.
3.00 p. m..	954	60,000	68.765	+ .005	1.180	20	373 ° C.
3.30 p. m..	954	60,000	68.775	+ .010	1.190	20	373° C.
4.00 p. m..	954	60,000	68.785	+ .010	1.200	20	373° C.
4.30 p. m..	954	60,000	68.785	0.000	1.200	30	Current off; 373° C.
4.37 p. m..	954	60,000	68.755	− .030	1.170	20	339° C.
4.51 p. m..	954	60,000	68.715	− .040	1.130	20	294° C.
Nov. 13:							
8.03 a. m..	954	60,000	68.540	− .175	.955	15	Room temperature.
9.22 a. m..	84	5,250	68.395	− .145	.810	20	

EXPERIMENT NO. 20.

[Final temperature, 378° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 15:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
8.48 a. m..	84	5,250	67.475	.....	.....	.....	Room temperature.
9.10 a. m..	954	60,000	67.610	+0.135	0.135	23	Room temperature; current on.
9.19 a. m..	954	60,000	67.650	+ .040	.175	23	96° C.
9.24 a. m..	954	60,000	67.685	+ .035	.210	23	136° C.
9.30 a. m..	954	60,000	67.795	+ .110	.320	23	186° C.
9.35 a. m..	954	60,000	67.945	+ .150	.470	23	222° C.
9.41 a. m..	954	60,000	67.990	+ .045	.515	23	259° C.
9.50 a. m..	954	60,000	68.060	+ .070	.585	23	305° C.
9.56 a. m..	954	60,000	68.110	+ .050	.635	23	339° C.
10.04 a. m..	954	60,000	68.190	+ .080	.715	23	373° C.
10.20 a. m..	954	60,000	68.240	+ .050	.765	23	373° C.
10.30 a. m..	954	60,000	68.255	+ .015	.780	23	373° C.
10.45 a. m..	954	60,000	68.270	+ .015	.795	23	378° C.
11.00 a. m..	954	60,000	68.280	+ .010	.805	23	373° C.
11.30 a. m..	954	60,000	68.290	+ .010	.815	23	373° C.
12.00 m.....	954	60,000	68.300	+ .010	.825	23	373° C.
12.30 p. m..	954	60,000	68.310	+ .010	.835	23	373° C.
1.00 p. m..	954	60,000	68.310	0.000	.835	23	373° C.
4.04 p. m..	954	60,000	68.360	+ .050	.885	21	373° C.; current off.
Nov. 16:							
8.00 a. m..	954	60,000	68.125	− .235	.650	26	Room temperature.
8.25 a. m..	84	5,250	67.990	− .135	.515	21	Do.

EXPERIMENT NO. 21.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Nov. 16:			*Cm.*	*Cm.*	*Cm.*	°*C.*	
10.03 a. m..	84	5,250	68.455	.....	.....	23	Room temperature.
10.38 a. m..	954	60,000	68.590	+0.135	0.135	24	Do.
11.15 a. m..	954	60,000	68.580	− .010	.125	24	Do.
11.25 a. m..	954	60,000	68.575	− .005	.120	24	Do.
12.00 m.....	954	60,000	68.575	0.000	.120	24	Do.
Nov. 17:							
8.10 a. m..	954	60,000	68.590	+ .015	.135	24	Do.
8.35 a. m..	954	60,000	68.590	0.000	.135	24	Room temperature; current on.
8.45 a. m..	954	60,000	68.665	+ .075	.210	24	135° C.
8.54 a. m..	954	60,000	68.730	+ .065	.275	24	186° C.
8.58 a. m..	954	60,000	68.790	+ .060	.335	24	222° C.
9.05 a. m..	954	60,000	68.850	+ .060	.395	24	259° C.
9.07 a. m..	954	60,000	68.875	+ .025	.420	24	271° C.
9.17 a. m..	954	60,000	68.885	+ .010	.430	24	271° C.
9.30 a. m..	954	60,000	68.890	+ .005	.435	24	271° C.
10.00 a. m..	954	60,000	68.890	0.000	.435	24	271° C.
10.30 a. m..	954	60,000	68.895	+ .005	.440	23	271° C.
11.00 a. m..	954	60,000	68.895	0.000	.440	23	271° C.
11.30 a. m..	994	60,000	68.895	0.000	.440	23	271° C.
12.00 m.....	954	60,000	68.900	+ .005	.445	23	271° C.
12.30 p. m..	954	60,000	68.895	− .005	.440	23	271° C.
1.00 p. m..	954	60,000	68.900	+ .005	.445	23	271° C.
1.30 p. m..	954	60,000	68.895	− .005	.440	23	271° C.
2.00 p. m..	954	60,000	68.900	+ .005	.445	23	271° C.
2.30 p. m..	954	60,000	68.900	0.000	.445	23	271° C.
3.07 p. m..	954	60,000	68.895	− .005	.440	23	271° C.; current off.
3.10 p. m..	954	60,000	68.880	− .015	.425	23	259° C.
3.30 p. m..	954	60,000	68.850	− .030	.395	23	210° C.
3.48 p. m..	954	60,000	68.830	− .020	.375	23	174° C.
4.15 p. m..	954	60,000	68.795	− .035	.340	23	135° C.
4.55 p. m..	954	60,000	68.775	− .020	.320	23	96° C.
Nov. 18:							
8.00 a. m..	954	60,000	68.730	− .045	.275	20	Room temperature.
8.15 a. m..	84	5,250	68.595	− .135	.140	20	Do.

EXPERIMENT NO. 22.

[Final temperature, 374° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*°C.*	
Nov. 18:							
9.21 a. m..	84	5,250	67.465	.....	.....	21	Room temperature.
9.40 a. m..	954	60,000	67.595	+0.130	0.130	21	Do.
9.45 a. m..	954	60,000	67.595	0.000	.130	21	Room temperature; current on.
9.54 a. m..	954	60,000	67.640	+ .045	.175	21	96° C
9.58 a. m..	954	60,000	67.675	+ .035	.210	21	136° C
10.07 a. m..	954	60,000	67.740	+ .065	.275	21	210° C.
10.15 a. m..	954	60,000	67.795	+ .055	.330	22	259° C.
10.23 a. m..	954	60,000	67.850	+ .055	.385	22	305° C.
10.30 a. m..	954	60,000	67.890	+ .040	.425	22	339° C.
10.35 a. m..	954	60,000	67.940	+ .050	.475	22	373° C.
10.45 a. m..	954	60,000	67.950	+ .010	.485	22	373° C.
11.00 a. m..	954	60,000	67.955	+ .005	.490	22	373° C.
11.30 a. m..	954	60,000	67.965	+ .010	.500	22	373° C.
12.00 m.....	954	60,000	67.975	+ .010	.510	22	373° C.
12.38 p. m..	954	60,000	67.975	0.000	.510	22	373° C.
1.00 p. m..	954	60,000	67.975	0.000	.510	22	373° C.
1.30 p. m..	954	60,000	67.980	+ .005	.515	23	373° C.
2.05 p. m..	954	60,000	67.980	0.000	.515	23	373° C.
2.30 p. m..	954	60,000	67.985	+ .005	.520	23	373° C.
3.00 p. m..	954	60,000	67.985	0.000	.520	23	373° C.
3.30 p. m..	954	60,000	67.990	+ .005	.525	23	373° C.
4.05 p. m..	954	60,000	68.000	+ .010	.535	23	374° C.
4.35 p. m..	954	60,000	67.995	− .005	.530	23	373° C.; current off.
4.42 p. m..	954	60,000	67.980	− .015	.515	23	339° C.
4.55 p. m..	954	60,000	67.935	− .045	.470	23	294° C.
Nov. 20:							
8.05 a. m..	954	60,000	67.755	− .180	.290	22	
8.25 a. m..	84	5,250	67.630	− .125	.165	22	

EXPERIMENT NO. 23.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*°C.*	
Nov. 20:							
9.54 a. m..	84	5,250	68.605	.....	.....	21	
10.15 a. m..	954	60,000	68.750	+0.145	0.145	21	Current on.
10.26 a. m..	954	60,000	68.790	+ .040	.185	21	96° C.
10.31 a. m..	954	60,000	68.815	+ .025	.210	21	135° C.
10.37 a. m..	954	60,000	68.870	+ .055	.265	21	186° C.
10.42 a. m..	954	60,000	68.905	+ .035	.300	22	222° C.
10.48 a. m..	954	60,000	68.940	+ .035	.335	22	259° C.
10.50 a. m..	954	60,000	68.950	+ .010	.345	22	271° C.
11.00 a. m..	954	60,000	68.975	+ .025	.370	22	271° C.
11.30 a. m..	954	60,000	68.975	0.000	.370	22	271° C.
12.00 m.....	954	60,000	68.975	0.000	.370	22	271° C.
1.00 p. m..	954	60,000	68.975	0.000	.370	22	271° C.
2.00 p. m..	954	60,000	68.970	− .005	.365	22	271° C.
3.00 p. m..	954	60,000	68.970	0.000	.365	22	271° C.
4.00 p. m..	954	60,000	68.970	0.000	.365	22	271° C.
4.50 p. m..	954	60,000	68.970	0.000	.365	22	271° C.; current off.
Nov. 21:							
8.01 a. m..	954	60,000	68.810	− .160	.205	24	Room temperature.
8.24 a. m..	84	5,250	68.670	− .140	.065	24	Do.

EXPERIMENT NO. 24.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*° C.*	
Nov. 23:							
11.07 a. m..	84	5,250	68.190	.....	.....	24	Room temperature.
Nov. 24:							
8.25 a. m..	600	37,500	68.275	+0.085	0.085	20	Do.
8.30 a. m..	600	37,500	68.275	0.000	.085	20	Current on; room temperature.
8.39 a. m..	600	37,500	68.310	+ .035	.120	20	96° C.
8.43 a. m..	600	37,500	68.350	+ .040	.160	20	135° C.
8.49 a. m..	600	37,500	68.385	+ .035	.195	20	186° C.
8.54 a. m..	600	37,500	68.415	+ .030	.225	20	222° C.
9.00 a. m..	600	37,500	68.440	+ .025	.250	20	259° C.
9.07 a. m..	600	37,500	68.475	+ .035	.285	20	300° C.
9.14 a. m..	600	37,500	68.505	+ .030	.315	20	339° C.
9.21 a. m..	600	37,500	68.530	+ .025	.340	20	373° C.
9.30 a. m..	600	37,500	68.530	0.000	.340	20	373° C.
10.00 a. m..	600	37,500	68.535	+ .005	.345	20	373° C.
10.30 a. m..	600	37,500	68.535	0.000	.345	20	373° C.
11.00 a. m..	600	37,500	68.535.	0.000	.345	21	373° C.
11.30 a. m..	600	37,500	68.535	0.000	.345	21	373° C.
12.00 m.....	600	37,500	68.535	0.000	.345	21	373° C.
12.27 p. m..	600	37,500	68.540	+ .005	.350	20	373° C.
1.00 p. m..	600	37,500	68.540	0.000	.350	21	373° C.
1.30 p. m..	600	37,500	68.540	0.000	.350	21	373° C.
2.05 p. m..	600	37,500	68.540	0.000	.350	21	373° C.
2.33 p. m..	600	37,500	68.540	0.000	.350	22	373° C.
3.00 p. m..	600	37,500	68.540	0.000	.350	22	373° C.
3.21 p. m..	600	37,500	68.540	0.000	.350	22	373° C.; current off.
3.30 p. m..	600	37,500	68.505	− .035	.315	22	334° C.
3.38 p. m..	600	37,500	68.490	− .015	.300	22	300° C.
3.55 p. m..	600	37,500	68.445	− .045	.255	22	259° C.
4.10 p. m..	600	37,500	68.420	− .025	.230	22	222° C.
4.26 p. m..	600	37,500	68.395	− .025	.205	22	186° C.
4.55 p. m..	600	37,500	68.365	− .030	.175	25	135° C.
Nov. 25:							
8.02 a. m..	600	37,500	68.295	− .070	.105	22	Room temperature.
8.20 p. m..	84	5,250	68.220	− .075	.030	22	Do.

EXPERIMENT NO. 25.

[Final temperature, 288° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*° C.*	
Nov. 25:							
9.25 a. m..	84	5,250	67.980	.....	.....	23	Room temperature.
9.44 a. m..	600	37,500	68.065	+0.085	0.085	23	Room temperature; current on.
9.53 a. m..	600	37,500	68.090	+ .025	.110	23	96° C.
9.57 a. m..	600	37,500	68.135	+ .045	.155	23	135° C.
10.03 a. m..	600	37,500	68.170	+ .035	.190	23	186° C.
10.10 a. m..	600	37,500	68.200	+ .030	.220	23	222° C.
10.17 a. m..	600	37,500	68.235	+ .035	.255	23	271° C.
1.42 p. m..	600	37,500	68.245	+ .010	.265	23	288° C.
1.50 p. m..	600	37,500	68.235	− .010	.255	23	271° C.
2.00 p. m..	600	37,500	68.235	0.000	.255	23	271° C.
2.30 p. m..	600	37,500	68.235	0.000	.255	23	271° C.
3.00 p. m..	600	37,500	68.235	0.000	.255	23	271° C.
3.30 p. m..	600	37,500	68.235	0.000	.255	23	271° C.
4.00 p. m..	600	37,500	68.235	0.000	.255	23	271° C.
4.17 p. m..	600	37,500	68.235	0.000	.255	23	271° C.; current off.
4.36 p. m..	600	37,500	68.195	− .040	.215	23	216° C.
4.55 p. m..	600	37,500	68.165	− .030	.185	23	180° C.
Nov. 27:							
8.01 a. m..	600	37,500	68.070	− .095	.090	23	Room temperature.
8.16 a. m..	84	5,250	67.995	− .075	.015	.....	Do.

EXPERIMENT NO. 26.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Nov. 27:							
10.05 a. m..	84	5,250	68.875	.....	.....	24	Room temperature.
Nov. 28:							
8.13 a. m..	84	5,250	68.875	0.000	0.000	24	Do.
8.34 a. m..	600	37,500	68.950	+ .075	.075	24	Room temperature; current on.
8.45 a. m..	600	37,500	69.000	+ .050	.125	24	56° C.
8.49 a. m..	600	37,500	69.025	+ .025	.150	24	135° C.
8.54 a. m..	600	37,500	69.060	+ .035	.185	24	186° C.
8.58 a. m..	600	37,500	69.090	+ .030	.215	24	222° C.
9.03 a. m..	600	37,500	69.115	+ .025	.240	24	259° C.
9.10 a. m..	600	37,500	69.155	+ .040	.280	24	305° C.
9.17 a. m..	600	37,500	69.185	+ .030	.310	24	339° C.
9.23 a. m..	600	37,500	69.215	+ .030	.340	24	373° C.
9.30 a. m..	600	37,500	69.215	0.000	.340	23	373° C.
10.00 a. m..	600	37,500	69.220	+ .005	.345	23	373° C.
10.30 a. m..	600	37,500	69.215	− .005	.340	22	373° C.
11.00 a. m..	600	37,500	69.215	0.000	.340	22	373° C.
11.30 a. m..	600	37,500	69.215	0.000	.340	22	373° C.
12.00 m.....	600	37,500	69.220	+ .005	.345	22	373° C.
1.00 p. m..	600	37,500	69.220	0.000	.345	22	373° C.
1.30 p. m..	600	37,500	69.220	0.000	.345	22	373° C.
2.00 p. m..	600	37,500	69.220	0.000	.345	22	373° C.
2.30 p. m..	600	37,500	69.225	+ .005	.350	22	373° C.
3.00 p. m..	600	37,500	69.225	0.000	.350	22	373° C.
3.23 p. m..	600	37,500	69.225	0.000	.350	22	373° C.; current off.
3.33 p. m..	600	37,500	69.195	− .030	.320	22	339° C.
3.41 p. m..	600	37,500	69.170	− .025	.295	22	305° C.
3.54 p. m..	600	37,500	69.130	− .040	.255	22	259° C.
4.09 p. m..	600	37,500	69.110	− .020	.235	22	228° C.
4.40 p. m..	600	37,500	69.070	− .040	.195	22	167° C.
4.55 p. m..	600	37,500	69.055	− .015	.180	23	146° C.
Nov. 29:							
8.04 a. m..	600	37,500	68.985	−.070	.110	24	Room temperature.
8.19 a. m..	84	5,250	68.900	− .085	.025	24	Do.

EXPERIMENT NO. 27.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	° *C.*	
Nov. 29:							
9.36 a. m..	84	5,250	69.165	.....	.....	23	Room temperature.
9.51 a. m..	600	37,500	69.250	+0.085	0.085	23	Room temperature; current on.
10.00 a. m..	600	37,500	69.295	+ .045	.130	23	96° C.
10.05 a. m..	600	37,500	69.330	+ .035	.165	23	135° C.
10.11 a. m..	600	37,500	69.350	+ .020	.185	23	186° C.
10.17 a. m..	600	37,500	69.380	+ .030	.215	23	222° C.
10.24 a. m..	600	37,500	69.420	+ .040	.255	23	271° C.
10.37 a. m..	600	37,500	69.420	0.000	.255	23	271° C.
11.00 a. m..	600	37,500	69.420	0.000	.255	23	271° C.
11.30 a. m..	600	37,500	69.420	0.000	.255	23	271° C.
4.30 p. m..	600	37,500	69.415	− .005	.250	23	271° C.; current off.
Dec. 1:							
8.05 a. m..	600	37,500	69.250	− .165	.085	23	Room temperature.
8.17 a. m..	84	5,250	69.175	− .075	.010	23	Do.

EXPERIMENT NO. 28.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 1:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.42 a. m..	84	5,250	68.395	.....	.....	22	Room temperature.
9.55 a. m..	600	37,500	68.475	+0.080	0.080	22	Room temperature; current on.
10.09 a. m..	600	37,500	68.520	+ .045	.125	22	96° C.
10.13 a. m..	600	37,500	68.550	+ .030	.155	22	135° C.
10.19 a. m..	600	37,500	68.590	+ .040	.195	22	186° C.
10.21 a. m..	600	37,500	68.610	+ .020	.215	22	222° C.
10.30 a. m..	600	37,500	68.640	+ .030	.245	22	259° C.
10.38 a. m..	600	37,500	68.675	+ .035	.280	22	300° C.
10.45 a. m..	600	37,500	68,700	+ .025	.305	22	339° C.
10.50 a. m..	600	37,500	68.735	+ .035	.340	22	373° C.
11.00 a. m..	600	37,500	68.740	+ .005	.345	22	373° C.
11.30 a. m..	600	37,500	68.740	0.000	.345	22	373° C.
12.00 m.....	600	37,500	68.740	0.000	.345	22	373° C.
12.30 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
1.00 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
1.30 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
2.00 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
2.30 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
3.30 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
4.25 p. m..	600	37,500	68.740	0.000	.345	22	373° C.
4.50 p. m..	600	37,500	68.740	0.000	.345	22	373° C.; current off.
5.00 p. m..	600	37,500	68.710	− .030	.315	22	328° C.
Dec. 2:							
7.58 a. m..	600	37,500	68.500	−. 210	.105	22	Room temperature.
8.10 a. m..	84	5,250	68.415	− .085	.020	22	Do.

EXPERIMENT NO. 29.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 2:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.06 a. m..	84	5,250	68.910	.....	.....	22	Room temperature.
9.35 a. m..	600	37,500	68.990	+0.080	0.080	22	Room temperature; current on.
9.45 a. m..	600	37,500	69.035	+ .045	.125	22	96° C.
9.50 a. m..	600	37,500	69.065	+ .030	.155	22	135° C.
9.55 a. m..	600	37,500	69.095	+ .030	.185	22	186° C.
10.00 a. m..	600	37,500	69.130	+ .035	.220	22	221° C.
10.08 a. m..	600	37,500	69.165	+ .035	.255	21	271° C.
10.30 a. m..	600	37,500	69.165	0.000	.255	21	271° C.
11.15 a. m..	600	37,500	69.165	0.000	.255	21	271° C.
11.45 a. m..	600	37,500	69.170	+ .005	.260	21	271° C.
12.30 p. m..	600	37,500	69.170	0.000	.260	21	271° C.
1.00 p. m..	600	37,500	69.170	0.000	.260	21	271° C.
1.40 p. m..	600	37,500	69.170	0.000	.260	21	271° C.
2.40 a. m..	600	37,500	69.170	0.000	.260	20	271° C.
3.10 p. m..	600	37,500	69.170	0.000	.260	20	271° C.
4.08 p. m..	600	37,500	69.170	0.000	.260	21	271° C.; current off.
4.28 p. m..	600	37,500	69.130	− .040	.220	22	221° C.
4.44 p. m..	600	37,500	69.110	− .020	.200	23	186. C.
Dec. 4:							
8.03 a. m..	600	37,500	69.000	− .110	.090	21	Room temperature.
8.13 a. m..	84	5,250	68.920	− .080	.010	21	Do.

EXPERIMENT NO. 30.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 4:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.16 a. m..	84	5,250	68.145	.....	.....	21	Room temperature.
9 32 a. m..	600	37,500	68.215	+0.070	0.070	21	Room temperature; current on.
9.42 a. m..	600	37,500	68.260	+ .045	.115	21	96° C.
9.48 a. m..	600	37,500	68.295	+ .035	.150	21	149° C.
9.53 a. m..	600	37,500	68.325	+ .030	.180	21	186° C.
9.59 a. m..	600	37,500	68.350	+ .025	.205	21	222° C.
10.05 a. m..	600	37,500	68.380	+ .030	.235	21	259° C.
10.14 a. m..	600	37,500	68.415	+ .035	.270	21	305° C.
10.23 a. m..	600	37,500	68.450	+ .035	.305	21	339° C.
10.30 a. m..	600	37,500	68.470	+ .020	.325	21	373° C.
11.00 a. m..	600	37,500	68.475	+ .005	.330	21	373° C.
11.30 a. m..	600	37,500	68.475	0.000	.330	21	373° C.
12.00 m.....	600	37,500	68.475	0.000	.330	21	373° C.
4.30 p. m..	600	37,500	68.475	0.000	.330	21	373° C.
Dec. 5:							
8.07 a. m..	600	37,500	68.245	− .230	.100	18	Room temperature.
8.19 a. m..	84	5,250	68.160	− .085	.015	18	Do.

EXPERIMENT NO. 31.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 6:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.30 a. m..	84	5,250	67.525	.....	.....	22	Room temperature.
9.45 a. m..	600	37,500	67.605	+0.080	0.080	22	Room temperature; current on.
9.54 a. m..	600	37,500	67.645	+ .040	.120	22	96° C.
9.58 a. m..	600	37,500	67.680	+ .035	.155	22	135° C.
10.04 a. m..	600	37,500	67.710	+ .030	.185	22	186° C.
10.09 a. m..	600	37,500	67.740	+ .030	.215	22	222° C.
10.17 a. m..	600	37,500	67.780	+ .040	.255	22	271° C.
10.30 a. m..	600	37,500	67.780	0.000	.255	21	271° C.
11.05 a. m..	600	37,500	67.780	0.000	.255	21	271° C.
11.30 a. m..	600	37,500	67.780	0.000	.255	21	271° C.
12.00 m.....	600	37,500	67.780	0.000	.255	22	271° C.
1.00 p. m..	600	37,500	67.780	0.000	.255	24	271° C.
1.30 p. m..	600	37,500	67.780	0.000	.255	24	271° C.
2.00 p. m..	600	37,500	67.780	0.000	.255	24	271° C.
2.40 p. m..	600	37,500	67.775	− .005	.250	24	271° C.
3.00 p. m..	600	37,500	67.775	0.000	.250	24	271° C.
3.35 p. m..	600	37,500	67.775	0.000	.250	23	271° C.
4.00 p. m..	600	37,500	67.780	+ .005	.255	24	271° C.
4.24 p. m..	600	37,500	67.780	0.000	.255	24	271° C.; current off.
4.43 p. m..	600	37,500	67.740	− .040	.215	24	222° C.
Dec. 7:							
8.05 a. m..	600	37,500	67.610	− .130	.085	24	Room temperature.
8.20 a. m..	84	5,250	67.530	− .080	.005	24	Do.

EXPERIMENT NO. 32.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 5:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.09 a. m..	84	5,250	66.725	.....	.....	21	Room temperature.
9.25 a. m..	600	37,500	66.800	+0.075	0.075	21	Room temperature; current on.
9.34 a. m..	600	37,500	66.850	+ .050	.125	21	96° C.
9.38 a. m..	600	37,500	66.870	+ .020	.145	21	135° C.
9.44 a. m..	600	37,500	66.905	+ .035	.180	21	186° C.
9.49 a. m..	600	37,500	66.940	+ .035	.215	21	222° C.
9.55 a. m..	600	37,500	66.965	+ .025	.240	21	259° C.
10.04 a. m..	600	37,500	66.995	+ .030	.270	21	305° C.
10.11 a. m..	600	37,500	67.025	+ .030	.300	21	339° C.
10.20 a. m..	600	37,500	67.055	+ .030	.330	21	373° C.
10.30 a. m..	600	37,500	67.055	0.000	.330	21	373° C.
11.00 a. m..	600	37,500	67.055	0.000	.330	20	373° C.
11.30 a. m..	600	37,500	67.055	0.000	.330	20	373° C.
12.00 m.....	600	37,500	67.055	0.000	.330	20	373° C.
1.00 p. m..	600	37,500	67.055	0.000	.330	21	373° C.
1.30 p. m..	600	37,500	67.055	0.000	.330	21	373° C.
2.00 p. m..	600	37,500	67.055	0.000	.330	23	373° C.
2.30 p. m..	600	37,500	67.060	+ .005	.335	23	373° C.
3.00 p. m..	600	37,500	67.060	0.000	.335	23	373° C.
3.40 p. m..	600	37,500	67.060	0.000	.335	23	373° C.
4.20 p. m..	600	37,500	67.060	0.000	.335	23	373° C.; current off.
4.29 p. m..	600	37,500	67.035	− .025	.310	23	339° C.
4.38 p. m..	600	37,500	67.000	− .035	.275	23	305° C.
4.55 p. m..	600	37,500	66.970	− .030	.245	23	259° C.
Dec. 6:							
8.02 a. m..	600	37,500	66.815	− .155	.090	23	Room temperature.
8.15 a. m..	84	5,250	66.745	− .070	.020	23	Do.

EXPERIMENT NO. 33.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 7:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.10 a. m..	84	5,250	68.150	.....	.....	21	Room temperature.
9.35 a. m..	600	37,500	68.230	+0.080	0.080	21	Room temperature; current on.
9.51 a. m..	600	37,500	68.325	+ .095	.175	21	173° C.
9.54 a. m..	600	37,500	68.340	+ .015	.190	21	198° C.
10.03 a. m..	600	37,500	68.380	+ .040	.230	21	247° C.
10.10 a. m..	600	37,500	68.395	+ .015	.245	21	271° C.
10.30 a. m..	600	37,500	68.395	0.000	.245	20	271° C.
11.07 a. m..	600	37,500	68.395	0.000	.245	20	271° C.
11.30 a. m..	600	37,500	68.400	+ .005	.250	20	271° C.
12.00 m.....	600	37,500	68.395	− .005	.245	20	271° C.
4.10 p. m..	600	37,500	68.395	0.000	.245	20	271° C.
Dec. 8:							
8.03 a. m..	600	37,500	68.235	− .160	.085	26	Room temperature.
8.17 a. m..	84	5,250	68.150	− .085	.000	26	Do.

EXPERIMENT NO. 37.

Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 8:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.14 a. m..	84	5,250	67.635	.....	.....	23	Room temperature.
9.30 a. m..	600	37,500	67.720	+0.085	0.085	23	Room temperature; current on.
9.39 a. m..	600	37,500	67.765	+ .045	.130	23	96° C.
9.44 a. m..	600	37,500	67.805	+ .040	.170	23	149° C.
9.49 a. m..	600	37,500	67.830	+ .025	.195	23	186° C.
9.53 a. m..	600	37,500	67.865	+ .035	.230	23	222° C.
9.58 a. m..	600	37,500	67.900	+ .035	.265	23	259° C.
10.05 a. m..	600	37,500	67.955	+ .055	.320	23	305° C.
10.12 a. m..	600	37,500	67.990	+ .035	.355	23	339° C.
10.19 a. m..	600	37,500	68.050	+ .060	.415	23	373° C.
10.30 a. m..	600	37,500	68.075	+ .025	.440	23	373° C.
11.00 a. m..	600	37,500	68.085	+ .010	.450	23	373° C.
11.40 a. m..	600	37,500	68.095	+ .010	.460	23	373° C.
12.00 m.....	600	37,500	68.100	+ .005	.465	23	373° C.
12.30 p. m..	600	37,500	68.100	0.000	.465	23	373° C.
1.00 p. m..	600	37,500	68.105	+ .005	.470	22	373° C.
1.30 p. m..	600	37,500	68.110	+ .005	.475	22	373° C.
2.00 p. m..	600	37,500	68.110	0.000	.475	23	373° C.
2.30 p. m..	600	37,500	68.115	+ .005	.480	23	373° C.
3.23 p. m..	600	37,500	68.120	+ .005	.485	22	373° C.
3.50 p. m..	600	37,500	68.120	0.000	.485	23	373° C.
4.19 p. m..	600	37,500	68.120	0.000	.485	23	373° C; current off.
4.29 p. m..	600	37,500	68.095	− .025	.460	23	339° C.
4.35 p. m..	600	37,500	68.065	− .030	.430	23	305° C.
4.53 p. m..	600	37,500	68.035	− .030	.400	24	259° C.
Dec. 9:							
8.03 a. m..	600	37,500	67,885	− .150	.250	20	Room temperature.
8.14 a. m..	84	5,250	67.790	− .095	.155	20	Do.

EXPERIMENT NO. 38.

[Final temperature, 351° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 9:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.10 a. m..	84	5,250	68.040	.....	.....	22	Room temperature.
9.28 a. m..	600	37,500	68.120	+0.080	0.080	22	Room temperature; current on.
9.35 a. m..	600	37,500	68.165	+ .045	.125	22	96° C
9.40 a. m..	600	37,500	68.210	+ .045	.170	22	149° C.
9.45 a. m..	600	37,500	68.245	+ .035	.205	22	186° C.
9.52 a. m..	600	37,500	68.280	+ .035	.240	22	234° C.
9.57 a. m..	600	37,500	68.320	+ .040	.280	22	271° C.
10.14 a. m..	600	37,500	68.415	+ .095	.375	23	351° C.
10.30 a. m..	600	37,500	68.445	+ .030	.405	23	351° C.
11.00 a. m..	600	37,500	68.450	+ .005	.410	23	351° C.
12.00 m.....	600	37,500	68.455	+ .005	.415	23	351° C.
1.05 p. m..	600	37,500	68.460	+ .005	.420	23	351° C.
1.35 p. m..	600	37,500	68.460	0.000	.420	23	351° C.
2.00 p. m..	600	37,500	68.460	0.000	.420	23	351° C.
2.40 p. m..	600	37,500	68.465	+ .005	.425	23	351° C.
3.25 p. m..	600	37,500	68.470	+ .005	.430	22	351° C.
4.14 p. m..	600	37,500	68.470	0.000	.430	22	351° C.
4.30 p. m..	600	37,500	68.415	− .055	.375	22	294° C.
4.37 p. m..	600	37,500	68.395	− .020	.355	22	271° C.
4.50 p. m..	600	37,500	68.380	− .015	.340	22	234° C.
Dec. 11:							
8.03 a. m..	600	37,500	68.245	− .135	.205	17	Room temperature.
8.13 a. m..	84	5,250	68.155	− .090	.115	17	Eoom temperature.

EXPERIMENT NO. 39.

[Final temperature, 300° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 11:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.08 a. m..	84	5,250	69.220	.....	.....	19	Room temperature.
9.19 a. m..	600	37,500	69.325	+0.105	0.105	19	Room temperature. current on.
9.19 a. m..	600	37,500	69.375	+ .050	.155	20	109° C.
9.33 a. m..	600	37,500	69.390	+ .015	.170	20	135° C.
9.40 a. m..	600	37,500	69.440	+ .050	.220	20	198° C.
9.49 a. m..	600	37,500	69.500	+ .060	.280	20	259° C.
9.56 a. m..	600	37,500	69.545	+ .045	.325	20	300° C.
10.05 a. m..	600	37,500	69.555	+ .010	.335	20	300° C.
10.30 a. m..	600	37,500	69.565	+ .010	.345	20	300° C.
11.00 a. m..	600	37,500	69.565	0.000	.345	21	300° C.
11.30 a. m..	600	37,500	69.565	0.000	.345	21	300° C.
12.00 m.....	600	37,500	69.565	0.000	.345	21	300° C.
1.00 p. m..	600	37,500	69.565	0.000	.345	22	300° C.
2.00 p. m..	600	37,500	69.575	+ .010	.355	22	300° C.
2.40 p. m..	600	37,500	69.575	0.000	.355	22	300° C.
3.30 p. m..	600	37,500	69.575	0.000	.355	22	300° C.
3.56 p. m..	600	37,500	69.575	0.000	.355	22	300° C.; current off.
4.10 p. m..	600	37,500	69.545	− .030	.325	22	259° C.
4.35 p. m..	600	37,500	69.500	− .045	.280	22	198° C.
Dec. 12:							
8.05 a. m..	600	37,500	69.400	− .100	.180	25	Room temperature.
8.16 a. m..	84	5,250	69.300	− .100	.080	25	Do.

EXPERIMENT NO. 40.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 12:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.25 a. m..	84	5,250	68.430	.....	.....	23	Room temperature.
9.34 a. m..	600	37,500	68.505	+0.075	0.075	23	Room temperature; current on.
9.44 a. m..	600	37,500	68.555	+ .050	.125	23	96° C.
9.47 a. m..	600	37,500	68.580	+ .025	.150	22	135° C.
9.54 a. m..	600	37,500	68.620	+ .040	.190	22	186° C.
9.59 a. m..	600	37,500	68.650	+ .030	.220	22	222° C.
10.06 a. m..	600	37,500	68.705	+ .055	.275	21	271° C.
10.30 a. m..	600	37,500	68.705	0.000	.275	21	271° C.
11.00 a. m..	600	37,500	68.710	+ .005	.280	21	271° C.
11.30 a. m..	600	37,500	68.710	0.000	.280	21	271° C.
12.00 m.....	600	37,500	68.710	0.000	.280	21	271° C.
1.00 p. m..	600	37,500	68.715	+ .005	.285	21	271° C.
1.40 p. m..	600	37,500	68.715	0.000	.285	21	271° C.
2.05 p. m..	600	37,500	68.720	+ .005	.290	21	271° C.
2.40 p. m..	600	37,500	68.720	0.000	.290	21	271° C.
3.10 p. m..	600	37,500	68.715	− .005	.285	21	271° C.
3.48 p. m..	600	37,500	68.715	0.000	.285	20	271° C.
4.06 p. m..	600	37,500	68.715	0.000	.285	20	271° C.; current off.
4.26 p. m..	600	37,500	68.685	− .030	.255	20	222° C.
4.43 p. m..	600	37,500	68.660	− .025	.230	20	186° C.
Dec. 13:							
8.03 a. m..	600	37,500	68.555	− .105	.125	21	Room temperature.
8.12 a. m..	84	5,250	68.465	− .090	.035	21	Do.

EXPERIMENT NO. 41.

[Final temperature, 228° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 13:			*Cm.*	*Cm.*	*Cm.*	° C.	
9.30 a. m..	84	5,250	67.640			22	Room temperature.
9.45 a. m..	600	37,500	67.735	+0.095	0.095	22	Room temperature; current on.
9.54 a. m..	600	37,500	67.770	+ .035	.130	22	96° C.
9.57 a. m..	600	37,500	67.800	+ .030	.160	22	135° C.
10.00 a. m..	600	37,500	67.845	+ .045	.205	22	186° C.
10.08 a. m..	600	37,500	67.880	+ .035	.240	22	228° C.
10.30 a. m..	600	37,500	67.885	+ .005	.245	22	228° C.
11.00 a. m..	600	37,500	67.890	+ .005	.250	22	228° C.
11.30 a. m..	600	37,500	67.890	0.000	.250	22	228° C.
12.00 m.....	600	37,500	67.885	− .005	.245	22	228° C.
12.30 p. m..	600	37,500	67.885	0.000	.245	22	228° C.
4.08 p. m..	600	37,500	67.885	0.000	.245	22	228° C.; current off.
Dec. 14:							
8.04 a. m..	600	37,500	67.755	− .130	.115	23	Room temperature.
8.18 a. m..	84	5,250	67.680	− .075	.040	23	Do.

EXPERIMENT NO. 42.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 15:			*Cm.*	*Cm.*	*Cm.*	° C.	
9.30 a. m..	84	5,250	68.040			21	Room temperature.
9.45 a. m..	758	47,500	68.165	+0.125	0.125	21	Room temperature; current on.
9.54 a. m..	758	47,500	68.215	+ .050	.175	21	109° C.
10.00 a. m..	758	47,500	68.260	+ .045	.220	21	173° C.
10.08 a. m..	758	47,500	68.295	+ .035	.255	21	222° C.
10.13 a. m..	758	47,500	68.335	+ .040	.295	21	259° C.
10.20 a. m..	758	47,500	68.395	+ .060	.355	21	305° C.
10.26 a. m..	758	47,500	68.440	+ .045	.400	21	339° C.
10.33 a. m..	758	47,500	68.515	+ .075	.475	21	373° C.
11.00 a. m..	758	47,500	68.540	+ .025	.500	21	373° C.
11.30 a. m..	758	47,500	68.555	+ .015	.515	21	373° C.
12.00 m.....	758	47,500	68.555	0.000	.515	22	373° C.
1.00 p. m..	758	47,500	68.565	+ .010	.525	23	373° C.
1.55 p. m..	758	47,500	68.570	+ .005	.530	23	373° C.
2.35 p. m..	758	47,500	68.575	+ .005	.535	23	373° C.
3.05 p. m..	758	47,500	68.585	+ .010	.545	23	373° C.
3.40 p. m..	758	47,500	68.590	+ .005	.550	23	373° C.
4.20 p. m..	758	47,500	68.590	0.000	.550	23	373° C.
4.33 p. m..	758	47,500	68.590	0.000	.550	23	373° C.; current off.
4.45 p. m..	758	47,500	68.560	− .030	.520	23	328° C.
4.50 p. m..	758	47,500	68.535	− .025	.495	23	305° C.
Dec. 16:							
8.09 a. m..	758	47,500	68.355	− .180	.315	22	Room temperature.
8.22 a. m..	84	5,250	68.250	− .105	.210	22	Do.

EXPERIMENT NO. 43.

[Final temperature, 300° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 16:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.26 a. m..	84	5,250	68.270	.....	.....	23	Room temperature.
9.38 a. m..	758	47,500	68.385	+0.115	0.115	23	Room temperature; current on.
9.46 a. m..	758	47,500	68.435	+ .050	.165	23	109° C.
9.55 a. m..	758	47,500	68.495	+ .060	.225	23	173° C.
10.02 a. m..	758	47,500	68.535	+ .040	.265	23	222° C.
10.06 a. m..	758	47,500	68.570	+ .035	.300	23	259° C.
10.15 a. m..	758	47,500	68.620	+ .050	.350	23	300° C.
10.35 a. m..	758	47,500	68.635	+ .015	.365	23	300° C.
11.00 a. m..	758	47,500	68.640	+ .005	.370	23	300° C.
11.30 a. m..	758	47,500	68.645	+ .005	.375	22	300° C.
11.55 a. m..	758	47,500	68.645	0.000	.375	22	300° C.
12.35 p. m..	758	47,500	68.650	+ .005	.380	22	300° C.
1.05 p. m..	758	47,500	68.650	0.000	.380	21	300° C.
1.35 p. m..	758	47,500	68.650	0.000	.380	22	300° C.
3.00 p. m..	758	47,500	68.655	+ .005	.385	22	300° C.
3.35 p. m..	758	47,500	68.655	0.000	.385	22	300° C.
3.55 p. m..	758	47,500	68.660	+ .005	.390	22	300° C.
4.15 p. m..	758	47,500	68.660	0.000	.390	22	300° C.; current off.
4.30 p. m..	758	47,500	68.620	− .040	.350	22	259° C.
4.44 p. m..	758	47,500	68.605	− .015	.335	22	222° C.
Dec. 18:							
8.03 a. m..	758	47,500	68.470	− .135	.200	20	Room temperature.
8.16 a. m..	84	5,250	68.360	− .110	.090	20	Do.

EXPERIMENT NO. 44.

[Final temperature, 350° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 18:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.21 a. m..	84	5,250	67.200	.....	.....	20	Room temperature.
9.40 a. m..	759	47,500	67.315	+0.115	0.115	20	Room temperature; current on.
9.54 a. m..	759	47,500	67.425	+ .110	.225	20	173° C.
10.04 a. m..	759	47,500	67.465	+ .040	.265	20	222° C.
10.10 a. m..	759	47,500	67.505	+ .040	.305	20	259° C.
10.18 a. m..	759	47,500	67.560	+ .055	.360	20	305° C.
10.27 a. m..	759	47,500	67.625	+ .065	.425	20	350° C.
10.40 a. m..	759	47,500	67.645	+ .020	.445	20	350° C.
11.00 a. m..	759	47,500	67.655	+ .010	.455	20	350° C.
11.15 a. m..	759	47,500	67.660	+ .005	.460	21	350° C.
11.30 a. m..	759	47,500	67.665	+ .005	.465	21	350° C.
12.00 m.....	759	47,500	67.670	+ .005	.470	21	350° C.
1.00 p. m..	759	47,500	67.675	+ .005	.475	21	350° C.
1.30 p. m..	759	47,500	67.675	0.000	.475	21	350° C.
2.00 p. m..	759	47,500	67.680	+ .005	.480	21	350° C.
2.30 p. m..	759	47,500	67.685	+ .005	.485	21	350° C.
3.15 p. m..	759	47,500	67.685	0.000	.485	22	350° C.
4.10 p. m..	759	47,500	67.685	0.000	.485	22	350° C.
4.27 p. m..	759	47,500	67.690	+ .005	.490	22	350° C.; current off.
4.40 p. m..	759	47,500	67.655	− .035	.455	22	305° C.
4.57 p. m..	759	47,500	67.625	− .030	.425	22	259° C.
Dec. 19:							
8.04 a. m..	759	47,500	67.470	− .155	.270	21	Room temperature.
8.20 a. m..	84	5,250	67.350	− .120	.150	22	Do.

EXPERIMENT NO. 45.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 19:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.24 a. m..	84	5,250	67.405	.....	.....	22	Room temperature.
9.45 a. m..	758	47,500	67.510	+0.105	0.105	22	Room temperature; current on.
9.56 a. m..	758	47,500	67.590	+ .080	.185	22	135° C.
10.08 a. m..	758	47,500	67.645	+ .055	.240	22	198° C.
10.14 a. m..	758	47,500	67.690	+ .045	.285	22	248° C.
10.17 a. m..	758	47,500	67.715	+ .025	.310	22	271° C.
10.30 a. m..	758	47,500	67.730	+ .015	.325	22	271° C.
11.00 a. m..	758	47,500	67.740	+ .010	.335	22	271° C.
11.40 a. m..	758	47,500	67.740	0.000	.335	23	271° C.
1.10 p. m..	758	47,500	67.740	0.000	.335	23	271° C.
1.40 p. m..	758	47,500	67.740	0.000	.335	23	271° C.
2.40 p. m..	758	47,500	67.740	0.000	.335	23	271° C.
3.05 p. m..	758	47,500	67.740	0.000	.335	23	271° C.
3.50 p. m..	758	47,500	67.740	0.000	.335	23	271° C.
4.17 p. m..	758	47,500	67.740	0.000	.335	23	271° C.; current off.
4.30 p. m..	758	47,500	67.720	− .020	.315	23	248° C.
4.50 p. m..	758	47,500	67.690	− .030	.285	23	198° C.
Dec. 20:							
8.07 a. m..	758	47,500	67.575	− .115	.170	23	Room temperature.
8.19 a. m..	84	5,250	67.475	− .100	.070	23	Do.

EXPERIMENT NO. 45A.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 19:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.24 a. m..	84	5,250	77.815	.....	.....	22	Room temperature.
9.45 a. m..	758	47,500	77.955	+0.140	0.140	22	Room temperature; current on.
9.56 a. m..	758	47,500	78.035	+ .080	.220	22	135° C.
10.08 a. m..	758	47,500	78.080	+ .045	.265	22	198° C.
10.14 a. m..	758	47,500	78.130	+ .050	.315	22	248° C.
10.17 a. m..	758	47,500	78.170	+ .040	.355	22	271° C.
10.30 a. m..	758	47,500	78.180	+ .010	.365	22	271° C.
11.00 a. m..	758	47,500	78.180	0.000	.365	22	271° C.
11.40 a. m..	758	47,500	78.180	0.000	.365	23	271° C.
1.10 p. m..	758	47,500	78.180	0.000	.365	23	271° C.
1.40 p. m..	758	47,500	78.180	0.000	.365	23	271° C.
2.40 p. m..	758	47,500	78.180	0.000	.365	23	271° C.
3.05 p. m..	758	47,500	78.180	0.000	.365	23	271° C.
3.50 p. m..	758	47,500	78.185	+ .005	.370	23	271° C.
4.17 p. m..	758	47,500	78.185	0.000	.370	23	271° C.; current off.
4.30 p. m..	758	47,500	78.165	− .020	.350	23	248° C.
4.50 p. m..	758	47,500	78.135	− .030	.320	23	198° C.
Dec. 20:							
8.05 a. m..	758	47,500	78.015	− .120	.200	23	Room temperature.
8.19 a. m..	84	5,250	77.890	− .125	.075	23	Do.

EXPERIMENT NO. 46.

[Final temperature, 222° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 20:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.09 a. m..	84	5,250	68.840	.....	.....	23	Room temperature.
9.36 a. m..	758	47,500	68.960	+0.120	0.120	23	Room temperature; current on.
9.45 a. m..	758	47,500	69.010	+ .050	.170	23	109° C.
9.54 a. m..	758	47,500	69,075	+ .065	.235	23	186° C.
10.00 a. m..	758	47,500	69.110	+ .035	.270	23	222° C.
10.15 a. m..	758	47,500	69.110	0.000	.270	23	222° C.
10.30 a. m..	758	47,500	69.110	0.000	.270	23	222° C.
11.00 a. m..	758	47,500	69.115	+ .005	.275	23	222° C.
11.30 a. m..	758	47,500	69.115	0.000	.275	23	222° C.
12.00 m.....	758	47,500	69.115	0.000	.275	23	222° C.
4.00 p. m..	758	47,500	69.115	0.000	.275	23	222° C.; current off.
Dec. 21:							
8.05 a. m..	758	47,500	68.995	− .120	.155	22	Room temperature.
8.18 a. m..	84	5,250	68.890	− .105	.050	22	Do..

EXPERIMENT NO. 47.

[Final temperature, 395° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 21:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
8.55 a. m..	84	5,250	67.945	.....	.....	22	Room temperature.
9.20 a. m..	758	47,500	68.050	+0.105	0.105	22	Room temperature; current on.
9.30 a. m..	758	47,500	68.100	+ .050	.155	22	96° C.
9.39 a. m..	758	47,500	68.175	+ .075	.230	22	186° C.
9.45 a. m..	758	47,500	68.255	+ .080	.310	23	222° C.
9.50 a. m..	758	47,500	68.315	+ .060	.370	24	259° C.
10.00 a. m..	758	47,500	68.390	+ .075	.445	23	305° C.
10.07 a. m..	758	47,500	68.445	+ .055	.500	23	339° C.
10.13 a. m..	758	47,500	68.515	+ .070	.570	23	395° C.
10.30 a. m..	758	47,500	68.565	+ .050	.620	23	395° C.
11.05 a. m..	758	47,500	68.595	+ .030	.650	23	395° C.
11.33 a. m..	758	47,500	68.615	+ .020	.670	23	395° C.
12.00 m.....	758	47,500	68.645	+ .030	.700	24	395° C.
12.30 p. m...	758	47,500	68.665	+ .020	.720	23	395° C.
1.05 p. m..	758	47,500	68.685	+ .020	.740	23	395° C.
2.30 p. m..	758	47,500	68.715	+ .030	.770	23	395° C.
3.00 p. m..	758	47,500	68.730	+ .015	.785	24	395° C.
3.30 p. m..	758	47,500	68.740	+ .010	.795	24	395° C.
4.00 p. m..	758	47,500	68.745	+ .005	.800	24	395° C.
4.13 p. m..	758	47,500	68.745	0.000	.800	24	395° C.: current off.
4.24 p. m..	758	47,500	68.720	− .025	.775	24	339° C.
4.32 p. m..	758	47,500	68.680	− .040	.735	24	305° C.
4.45 p. m..	758	47,500	68.655	− .025	.710	24	259° C.
4.58 p. m..	758	47,500	68.620	− .035	.675	23	222° C.
Dec. 22:							
8.04 a. m..	758	47,500	68.475	− .145	.530	20	Room temperature.
8.16 a. m..	84	5,250	68.370	− .105	.425	20	Do.

EXPERIMENT NO. 48.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 27:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.10 a. m..	84	5,250	67.770	.....	.....	20	Room temperature.
9.25 a. m..	758	47,500	67.875	+0.105	0.105	20	Room temperature; current on.
9.33 a. m..	758	47,500	67.920	+ .045	.150	20	96° C.
9.38 a. m..	758	47,500	67.955	+ .035	.185	20	149° C.
9.42 a. m..	758	47,500	68.020	+ .065	.250	20	198° C.
9.51 a. m..	758	47,500	68.170	+ .150	.400	20	259° C.
9.59 a. m..	758	47,500	68.255	+ .085	.485	20	317° C.
10.11 a. m..	758	47,500	68.365	+ .110	.595	20	373° C.
10.30 a. m..	758	47,500	68.405	+ .040	.635	20	373° C.
11.10 a. m..	758	47,500	68.435	+ .030	.665	22	373° C.
11.45 a. m..	758	47,500	68.445	+ .010	.675	22	373° C.
1.00 p. m..	758	47,500	68.445	0.000	.675	22	373° C.
1.30 p. m..	758	47,500	68.460	+ .015	.690	22	373° C.
2.30 p. m..	758	47,500	68.475	+ .015	.705	22	373° C.
3.30 p. m..	758	47,500	68.485	+ .010	.715	22	373° C.
4.12 p. m..	758	47,500	68.490	+ .005	.720	23	373° C.; current off.
4.29 p. m..	758	47,500	68.440	− .050	.670	23	317° C.
4.48 p. m..	758	47,500	68.395	− .045	.625	23	259° C.
Dec. 28:							
8.04 a. m..	758	47,500	68.250	− .145	.480	24	Room temperature.
8.20 a. m..	84	5,250	68.145	− .105	.375	24	Do.

EXPERIMENT NO. 49.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 28:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.10 a. m..	84	5,250	68.095	.....	.....	22	Room temperature.
9.28 a. m..	758	47,500	68.215	+0.120	0.120	22	Room temperature; current on.
9.37 a. m..	758	47,500	68.255	+ .040	.160	22	96° C.
9.42 a. m..	758	47.500	68.285	+ .030	.190	22	135° C.
9.49 a. m..	758	47,500	68.330	+ .045	.235	22	198° C.
10.00 a. m..	758	47,500	68.390	+ .060	.295	22	271° C.
10.05 a. m..	758	47,500	68.420	+ .030	.325	22	305° C.
10.12 a. m..	758	47,500	68.450	+ .030	.355	22	339° C.
10.21 a. m..	758	47,500	68.485	+ .035	.390	22	373° C.
10.30 a. m..	758	47,500	68.490	+ .005	.395	22	373° C.
11.00 a. m..	758	47,500	68.490	0.000	.395	21	373° C.
12.25 p. m..	758	47,500	68.490	0.000	.395	20	373° C.
1.00 p. m..	758	47,500	68.495	+ .005	.400	20	373° C.
2.15 p. m..	758	47,500	68.495	0.000	.400	23	373° C.
2.40 p. m..	758	47,500	68.500	+ .005	.405	23	373° C.
3.15 p. m..	758	47,500	68.500	0.000	.405	23	373° C.
3.48 p. m..	758	47,500	68.500	0.000	.405	23	373° C.
4.21 p. m..	758	47,500	68.500	0.000	.405	23	373° C.; current off.
4.30 p. m..	758	47,500	68.475	− .025	.380	23	339° C.
4.41 p. m..	758	47,500	68.440	− .035	.345	23	294° C.
4.55 p. m..	758	47,500	68.410	− .030	.315	23	259° C.
Dec. 29:							
8.05 a. m..	758	47,500	68.265	− .145	.170	23	Room temperature.
8.25 a. m..	84	5,250	68.145	− .120	.050	23	Do.

EXPERIMENT NO. 50.

[Final temperature, 300° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*° C.*	
Dec. 29:							
9.20 a. m..	84	5,250	68.395	.....	.....	23	Room temperature.
9.37 a. m..	758	47,500	68.505	+0.110	0.110	23	Room temperature; current on.
9.46 a. m..	758	47,500	68.555	+ .050	.160	23	96° C.
9.50 a. m..	758	47,500	68.580	+ .025	.185	23	135° C.
9.57 a. m..	758	47,500	68.625	+ .045	.230	23	198° C.
10.05 a. m..	758	47,500	68.675	+ .050	.280	23	259° C.
10.12 a. m..	758	47,500	68.710	+ .035	.315	24	300° C.
10.30 a. m..	758	47,500	68.710	0.000	.315	24	300° C.
11.00 a. m..	758	47,500	68.710	0.000	.315	24	300° C.
11.30 a. m..	758	47,500	68.705	− .005	.310	24	300° C.
12.00 m.....	758	47,500	68.705	0.000	.310	24	300° C.
1.00 p. m..	758	47,500	68.705	0.000	.310	23	300° C.
1.30 p. m..	758	47,500	68.705	0.000	.310	24	300° C.
2.00 p. m..	758	47,500	68.705	0.000	.310	24	300° C.
2.30 p. m..	758	47,500	68.705	0.000	.310	22	300° C.
3.00 p. m..	758	47,500	68.705	0.000	.310	22	300° C.
3.30 p. m..	758	47,500	68.705	0.000	.310	20	300° C.
4.12 p. m..	758	47,500	68.705	0.000	.310	20	300° C.; currnet off.
4.26 p. m..	758	47,500	68.670	− .035	.275	22	259° C.
4.40 p. m..	758	47,500	68.650	− .020	.255	22	222° C.
4.50 p. m..	758	47,500	68.630	− .020	.235	22	198° C.
Dec. 30:							
8.03 a. m..	758	47,500	68.520	− .110	.125	17	Room temperature.
8.19 a. m..	84	5,250	68.410	− .110	.015	18	Do.

EXPERIMENT NO. 51.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
			Cm.	*Cm.*	*Cm.*	*° C.*	
Dec. 30:							
9.13 a. m..	84	5,250	67.625	.....	.....	20	Room temperature.
9.28 a. m..	758	47,500	67.735	+0.110	0.110	20	Room temperature; current on.
9.43 a. m..	758	47,500	67.830	+ .095	.205	20	161° C.
9.48 a. m..	758	47,500	67.870	+ .040	.245	20	210° C.
9.56 a. m..	758	47,500	67.915	+ .045	.290	20	271° C.
10.35 a. m..	758	47,500	67.915	0.000	.290	20	271° C.
11.00 a. m..	758	47,500	67.915	0.000	.290	21	271° C.
11.55 a. m..	758	47,500	67.915	0.000	.290	22	271° C.
1.00 p. m..	758	47,500	67.915	0.000	290	22	271° C.
2.00 p. m..	758	47,500	67.915	0.000	.290	22	271° C.
3.00 p. m..	758	47,500	67.915	0.000	.290	22	271° C.
3.30 p. m..	758	47,500	67.915	0.000	.290	22	271° C.
3.56 p. m..	758	47,500	67.915	0.000	.290	22	271° C.; current off.
4.20 p. m..	758	47,500	67.865	− .050	.240	22	210° C.
4.47 p. m..	758	47,500	67.830	− .035	.205	22	161° C.
1917.							
Jan. 1:							
8.05 a. m..	758	47,500	67.745	− .085	.120	24	Room temperature.
8.12 a. m..	84	5,250	67.640	− .105	.015	24	Do.

EXPERIMENT NO. 53.

[Final temperature, 373° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 23:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
8.55 a. m..	84	5,250	67.525	.....	.....	22	Room temperature.
9.13 a. m..	758	47,500	67.640	+0.115	0.115	22	Room temperature; current on.
9.21 a. m..	758	47,500	67.680	+ .040	.155	22	96° C.
9.25 a. m..	758	47,500	67.725	+ .045	.200	22	135° C.
9.30 a. m..	758	47,500	67.755	+ .030	.230	22	186° C.
9.35 a. m..	758	47,500	67.790	+ .035	.265	23	222° C.
9.40 a. m..	758	47,500	67.820	+ .030	.295	23	259° C.
9.50 a. m..	758	47,500	67.885	+ .065	.360	23	316° C.
9.58 a. m..	758	47,500	67.945	+ .060	.420	23	373° C.
10.15 a. m..	758	47,500	67.955	+ .010	.430	22	373° C.
10.30 a. m..	758	47,500	67.960	+ .005	.435	22	373° C.
11.00 a. m..	758	47,500	67.965	+ .005	.440	22	373° C.
11.30 a. m..	758	47,500	67.970	+ .005	.445	23	373° C.
12.00 m.....	758	47,500	67.970	0.000	.445	23	373° C.
1.00 p. m..	758	47,500	67.980	+ .010	.455	24	373° C.
1.30 p. m..	758	47,500	67.985	+ .005	.460	23	373° C.
2.00 p. m..	758	47,500	67.990	+ .005	.465	24	373° C.
2.35 p. m..	758	47,500	67.995	+ .005	.470	24	373° C.
3.10 p. m..	758	47,500	67.995	0.000	.470	24	373° C.
3.40 p. m..	758	47,500	67.995	0.000	.470	24	373° C.
3.58 p. m..	758	47,500	67.995	0.000	.470	24	373° C.; current off.
4.09 p. m..	758	47,500	67.960	− .035	.435	24	339° C.
4.16 p. m..	758	47,500	67.945	− .015	.420	24	305° C.
4.32 p. m..	758	47,500	67.905	− .040	.380	24	259° C.
4.46 p. m..	758	47,500	67.880	− .025	.355	24	222° C.
Dec. 26:							
8.05 a. m..	758	47,500	67.745	− .135	.220	27	Room temperature.
8.18 a. m..	84	5,250	67.635	− .110	.110	24	Do.

EXPERIMENT NO. 54.

[Final temperature, 271° C.]

Time.	Load (pounds).	Load (pounds per square inch).	Length of wire between marks.	Change in length.	Total extension.	Temperature of room.	Temperature of furnace.
Dec. 26:			*Cm.*	*Cm.*	*Cm.*	° *C.*	
9.08 a. m..	84	5,250	67.630	.....	.....	22	Room temperature.
9.28 a. m..	758	47,500	67.745	+0.115	0.115	23	Room temperature; current on.
9.37 a. m..	758	47,500	67.800	+ .055	.170	22	109° C.
9.42 a. m..	758	47,500	67.840	+ .040	.210	22	149° C.
9.46 a. m..	758	47,500	67.870	+ .030	.240	21	186° C.
9.53 a. m..	758	47,500	67.900	+ .030	.270	21	234° C.
9.58 a. m..	758	47,500	67.940	+ .040	.310	22	271° C.
10.15 a. m..	758	47,500	67.945	+ .005	.315	21	271° C.
10.30 a. m..	758	47,500	67.945	0.000	.315	22	271° C.
11.10 a. m..	758	47,500	67.945	0.000	.315	22	271° C.
11.48 a. m..	758	47,500	67.950	+ .005	.320	22	271° C.
1.00 p. m..	758	47,500	67.950	0.000	.320	21	271° C.
1.30 p. m..	758	47,500	67.945	− .005	.315	20	271° C.
2.50 p. m..	758	47,500	67.945	0.000	.315	20	271° C.
3.35 p. m..	758	47,500	67.945	0.000	.315	22	271° C.
3.58 p. m..	758	47,500	67.945	0.000	.315	22	271° C.; current off.
4.14 p. m..	758	47,500	67.915	− .030	.315	23	234° C.
4.32 p. m..	758	47,500	67.885	− .030	.255	23	186° C.
4.58 p. m..	758	47,500	67.865	− .020	.235	24	149° C.
Dec. 27:							
8.03 a. m..	758	47,500	67.775	− .090	.145	24	Room temperature.
8.21 a. m..	84	5,250	67.675	− .100	.045	24	Do.

211–1

211-2

HOT CHISELS.

OBJECT.

The object of this investigation was to determine the relative merits of hand and machine made chisels. Four chisels were to be tested out in service in the smith shop for 30 days, after which drillings were to be taken and chemical analyses made.

The first test was very inconclusive as the original marks on the chisels were not removed and the personal element was very evident in the smith shop report.

In consequence of the above, four more chisels were ordered to be put through a similar test after first being submitted to the laboratory for examination.

CONCLUSIONS.

The behavior of the four chisels tested was as follows:

The blacksmiths were unable to detect any difference between the chisels, and found them all satisfactory when properly dressed and tempered, so that there is no reason for not purchasing machine-made chisels in the future, provided that the steel used in their manufacture is of the proper chemical composition.

The chisels all showed better heat treatment as received than after redressing and use in the smith shop.

EXPERIMENTAL.

The four chisels submitted to the laboratory were marked as follows, the maker's name being removed:

W. A. No.	Hand or machine made.
1	Hand-made.
2	Machine-made.
3	Hand-made.
4	Machine-made.

The chisels were polished for about 2 inches back from the cutting edge. Photograph No. 3589, taken from the chisels as received, shows the hardened zone of each chisel near the cutting edge. The structures were all excellent, the body of chisel 4 being slightly coarser than any of the other chisels.

Photograph No. 3590 shows the appearance of chisels Nos. 1, 3, and 4 after their return from the smith shop. Chisel No. 2 was not photographed at this time, but subsequent examination showed it to be very similar in structure to No. 1. This set of chisels was returned in much better condition structurally than the previous set tested. The appearance of the chisels after test only emphasizes the necessity of making chisel treatment a tool-room proposition.

The chemical analysis of the four chisels was as follows:

Marks.	C.	Mn.	Si.	S.	P.
No. 1	0.76	0.12	0.169	0.020	0.009
No. 2	.70	.37	.090	.036	.025
No. 3	.81	.18	.324	.045	.023
No. 4	.66	.39	.069	.028	.027

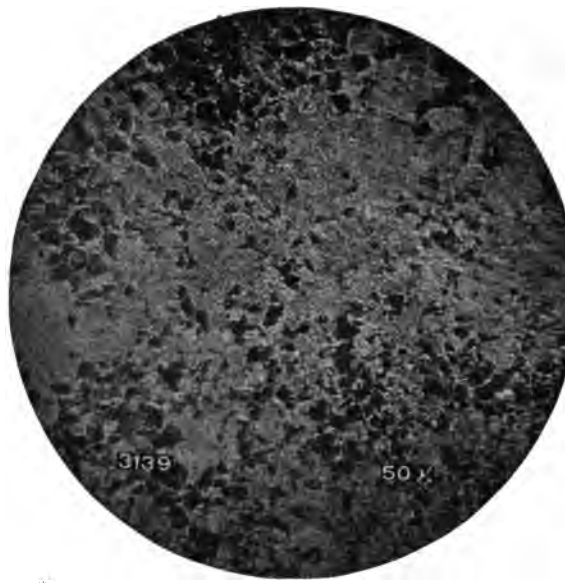
All are of excellent composition in respect to the elements other than carbon. Chisels No. 2 and No. 4 are probably lower in carbon than would be recommended for hot chisels, although the slightly higher manganese would in some degree offset their lack of "hardening power" due to their lower carbon.

REPORT ON THE RELATIVE MERITS OF HAND-MADE AND MACHINE-MADE CHISELS BASED ON BEHAVIOR IN USE IN SMITH SHOP OF SAMPLES PURCHASED FROM PRIVATE MANUFACTURERS.

W. A. No.	Hand or machine made.	Remarks.
1	Hand-made	Was used on regular work and found satisfactory; was redressed by blacksmith, and when again used a chip flew from head of chisel, showing faulty heat treatment given by blacksmith.
2	Machine-made	This chisel was too large for ordinary work and was consequently slighted by the blacksmith and little used. A special test was made on hard steel scrap, the chisel giving satisfactory service.
3	Hand-made	This chisel was used on regular work, and was redressed repeatedly, until the chisel was practically used up; behavior satisfactory.
4	Machine-made	This chisel was also nearly used up on regular work and found satisfactory.

CONCLUSION.

That this test was a fair one because the blacksmith using these chisels did not know which were machine-made and which were hand-made, nor that any of them were machine-made. The blacksmiths were unable to detect any difference between the chisels, and found them all satisfactory when properly dressed and tempered, so that there is no reason for not purchasing machine-made chisels in the future, provided that the steel used in their manufacture is of the proper chemical composition.


3139
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3169
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NOTES ON THE TRIANGULATED STRUCTURE DEVELOPED IN CERTAIN NICKEL STEELS.

In the "Tests of Metals, 1916," the report dealing with 14-inch gun bushing, model 1910, No. 9, described a triangular structure which occurred in the threads of the bushing, and other portions adjacent to the outer and inner circumference. The conclusion given in this report was as follows:

"The structure developed in the bushing under examination was in all probability developed by overheating previous to the quenching in oil."

Further remarks concerning this structure were made on page 48 of this report as follows:

Par. 2. "The cracks occurred in the triangular structure."

Par. 3. "Cracks occurred in sections of the bushing after they had been removed from same, showing beyond doubt the existence of internal strains."

Par. 4. "The defective structure existing in the bushing was decidedly more prevalent in the portions nearer the outer and inner circumferences of the forgings."

Par. 5. "Analysis showed that the portions of the bushing in which the light triangular structure predominated were lower in both carbon and chromium than the portions in which the polyhedral structure prevailed."

Par. 8. "The ultimate conclusion is that the forging from which this bushing was made was slightly decarburized to some depth by the forging, annealing, and quenching heats. The heating for quenching was carried on at too elevated a temperature, and upon quenching the defective structure was produced in the portions of the bushing in which the carbon had been reduced by decarburization, or possibly by diffusion."

Micrographs 3139 and 3169, on the opposite page, show the typical appearance of the triangular structure discussed above.

In the report above referred to, several tentative conclusions were drawn up, which will be repeated in part:

No. 1. "For any given composition of a pearlitic steel there exists certain temperature ranges, 'time of soaking' in these ranges, combined with certain rates of cooling down to and through the critical range, which are the most productive of the separation of the excess constituent to the cleavage planes of the original austenite crystals."

No. 2. "For any given rate of cooling from a given temperature there exists a certain critical composition of a steel which is more susceptible to the rejection of the excess constituent to the cleavage planes on cooling."

No. 3. "As special alloying elements change the solubility of carbon in austenite, it is to be expected that an element such as nickel will alter the critical composition of carbon necessary to

produce the triangular arrangement of the constituents, other conditions remaining constant."

No. 7. "If a nickel steel containing 3.50 per cent nickel and .35 carbon is cooled under the same conditions ferrite will not begin to separate until a lower temperature is reached, as the critical points are lowered by the presence of nickel."

To give some additional data on the formation of the triangular arrangement discussed above, a series of experiments was carried out on a steel of the following composition:

	Per cent.
C	0.34
Mn	.56
Si	.150
S	.031
P	.034
Ni	3.46
Cr	.18

The steel used was in the form of 1 inch round bar stock. A number of specimens were cut from the bar and a one-sixteenth-inch hole was drilled to a depth of one-half inch in each specimen for the insertion of a thermocouple. The specimen was heated to the desired temperature, held at this temperature for the chosen period of time, and then cooled either in the air or in the furnace, a cooling curve being obtained for each specimen. The apparatus to obtain the cooling curves consisted of a millivoltmeter and platinum-platinum rhodium couple for temperature measurements. The time taken for the specimen to cool 10° was noted, and the curves plotted from the data thus obtained. It is understood that the accuracy of this system was not great, but it is thought the errors will all fall within ±10° C.

CONCLUSIONS.

The triangular arrangement of ferrite and the constituent containing carbon was developed by heating to a high temperature, followed by air cooling. Holding the piece at the maximum temperature assisted materially in developing the triangular structure.

In no case, regardless of time of soaking, was the structure developed when the temperature did not exceed 800° C. As quenching a large piece in oil will at least approximate the same cooling conditions as were obtained by cooling a small specimen in air, it seems established that the tentative conclusions advanced in the report of "Tests of Metals" for 1916 are supported, namely, the heating for quenching was carried on at too elevated a temperature.

TREATMENTS USED.

1. Heated to 800° C., followed by (1) furnace cooling; (2) air cooling.
2. Heated to 900° C., followed by (1) furnace cooling; (2) air cooling.
3. Heated to 1,000° C., followed by (1) furnace cooling; (2) air cooling.
4. Heated to 1,100° C., followed by (1) furnace cooling; (2) air cooling.

5. Heated to 800° C., held at this temperature 1 hour, followed by (1) furnace cooling; (2) air cooling.
6. Heated to 900° C., held at this temperature 1 hour, followed by (1) furnace cooling; (2) air cooling.
7. Heated to 1,000° C., held at this temperature 1 hour, followed by (1) furnace cooling; (2) air cooling.
8. Heated to 1,100° C., held at this temperature 1 hour, followed by (1) furnace cooling; (2) air cooling.
9. Heated to 800° C., held at this temperature 6 hours, followed by(1) furnace cooling; (2) air cooling.
10. Heated to 900° C., held at this temperature 6 hours, followed by (1) furnace cooling; (2) air cooling
11. Heated to 1,000° C., held at this temperature 6 hours, followed by (1) furnace cooling; (2) air cooling.
12. Heated to 1,100° C., held at this temperature 6 hours, followed by (1) furnace cooling; (2) air cooling.

The cooling curves and micrographs at 50 and 500 diameters, respectively, are recorded herein. To assist in the presentation of the data, the structures developed by heating to 800°, 900°, 1,000° and 1,100° C., followed by furnace cooling, are recorded on plates facing page 220; the structures developed by heating to 800°, 900°, 1,000° and 1,100° C., followed by air cooling, on plates facing page 221, or, in other words, the maximum temperature is made the variable in each series.

DISCUSSION OF RESULTS—MICROGRAPHS.

Distinct triangulation has occurred in the following specimens:

	Plate.
X=1,100° C., 6 hours, air	225–4
W=1,000° C., 6 hours, air	225–3
V= 900° C., 6 hours, air	225–2
P=1,100° C., 1 hour, air	223–4
O=1,000° C., 1 hour, air	223–3
N= 900° C., 1 hour, air	223–2
H=1,100° C., 0 hour, air	221–4
G=1,000° C., 0 hour, air	221–3

No appreciable triangulation occurred under any conditions of soaking when the maximum temperature of heating did not exceed 800° C. Although no triangulation occurred at 900° C., when the time of soaking was nil, soaking 1 hour did produce the triangulated structure.

The triangulation is very sharp and distinct in specimens

	Plate.
X=1,100° C., 6 hours, air	225–4
W=1,000° C., 6 hours, air	225–3
V= 900° C., 6 hours, air	225–2
P=1,100° C., 1 hour, air	223–4
O=1,000° C., 1 hour, air	223–3
H=1,100° C., 0 hour, air	221–4

whereas in specimens

N= 900° C., 1 hour, air	223–2
G=1,000° C., 0 hour, air	221–3

it is not so well defined. In other words, as the time of soaking at the maximum temperature increases, the maximum temperature required to give the triangulated structure becomes less.

Certain of the furnace-cooled specimens show a decided tendency toward triangulation. The excess ferrite which would normally be rejected to the boundary lines of the grains is less in amount than would be expected from a steel of this carbon content. The specimens enumerated below show this tendency.

	Plate.
T=1,100° C., 6 hours, furnace	224.4
S=1,000° C., 6 hours, furnace	224–3
R= 900° C., 6 hours, furnace	224–2
L=1,100° C., 1 hour, furnace	222–4
K=1,000° C., 1 hour, furnace	222–3
J= 900° C., 1 hour, furnace [1]	222–2
D=1,100° C., 0 hour, furnace	220–4
C=1,000° C., 0 hour, furnace	220–3

As the treatment of this group of specimens differs only in rate of cooling from the air-cooled list previously given, in which all showed decided triangulation, it would seem entirely plausible to state that the increase in rate of cooling (air versus furnace) has only exaggerated a tendency previously existing. Stated in another manner, heating to a high maximum temperature, or soaking at a relatively high temperature, is essential to produce triangulation of the constitutents.

It is also to be noted that the dark constituent occurring in conjunction with the triangulated structure in the air-cooled specimens increases in amount the lower the maximum temperature of heating, and also the less the time of soaking at a given temperature.

A relative classification of grain size has also been made of the furnace-cooled samples, as follows:

	Plate.
Fine grained (maximum size established by specimen B)	220–2
Course grained (minimum size established by specimen S)	224–3
Medium grained (between limits of fine and course)	222–2
Fine grained:	
A= 800° C., 0 hour, furnace	220–1
B= 900° C., 0 hour, furnace	220–2
I= 800° C., 1 hour, furnace	222–1
Medium grained:	
C =1,000° C., 0 hour, furnace	220–3
K=1,000° C., 1 hour, furnace	222–3
J= 900° C., 1 hour, furnace	222–2
Q= 800° C., 6 hours, furnace	224–1
R= 900° C., 6 hours, furnace	224–2
Course grained:	
D=1,100° C., 0 hour, furnace	220–4
L=1,100° C., 1 hour, furnace	222–4
S=1,000° C., 6 hours, furnace	224–3
T=1,100° C., 6 hours, furnace	224–4

From an inspection of this rough classification, it is evident that time of soaking and maximum temperature both influence the grain size.

[1] Shows slight tendency toward triangulation.

The following specimens have approximately the same grain size:

	Plate.
D=1,100° C., 0 hours, furnace	220–4
L=1,100° C., 1 hour, furnace	222–4
S=1,000° C., 6 hours, furnace	224–3
T=1,100° C., 6 hours, furnace	224–4

This is of interest since it is in direct contradiction to statements made by some authorities. The fact seems evident that soaking at 1,100° C. has not produced any enlargement of the grain over that caused by heating to this temperature.

Soaking at lower temperatures does show enlargement of grain size, but once the maximum size is reached, further soaking at the temperature which gives the maximum size is apparently without effect.

A brief discussion of the cooling curves will be of interest. Examining first the furnace-cooled series in which the time of soaking was zero (p. 220) two critical points are apparent, the upper or A_r 3–2 point, which locates the beginning of the separation of free ferrite, and the lower or A_r–1 point, which locates the formation of pearlite or sorbite from the remaining austenite.

As these cooling curves are plotted between θ = temperature and $\frac{dt}{d\theta}$ the area included in the peak of the curve will be proportional to the energy liberated at that point.

Bearing this in mind, an inspection of this series of curves will show (1) that the reaction taking place at A_r 3–2 increases in amount as the maximum temperature of heating is decreased, (2) the reaction taking place at A_r–1 decreases as the maximum temperature of heating decreases.

We should, therefore, find more excess ferrite in the specimen heated to 800° C. and slowly cooled, than in the specimen heated to 1,100° and furnace cooled. An inspection of the micrographs of specimens D and A (p. 220) will verify this conclusion.

An inspection of the curves on page 222 (samples soaked one hour) and also the curves on page 224, (samples soaked six hours) will verify the conclusions previously advanced, namely, the higher the maximum temperature of heating the smaller is Q 3–2, the quantity of heat liberated at the A_r 3–2 point, and the larger Q 1, the quantity of heat liberated at the A_r 1 point. The amount of rejected ferrite is proportional to Q 3–2 and the amount of pearlite or sorbite proportional to Q 1.

Examining next the air-cooled specimens in which the time of soaking was zero (p. 221) it is found (1) that in general two critical points exist; (2) these points are approximately 100° lower in the air-cooled specimens than in the furnace-cooled ones.

The time temperature curve on page 219 shows the relative rate obtained by the two methods employed. It required approximately twelve times as long for the furnace-cooled specimen to reach 600° C. as was required for the air-cooled specimen.

A further inspection of the curves on page 221 will show that the A_r 3–2 point increases in volume as the maximum temperature of heating is decreased. Also the A_r 1 point diminishes in volume as the maximum temperature of heating is decreased. Curve E

does not show any lower point. As this did not occur in other specimens heated to 800°, no attention was given this irregularity.

Examination of the curves on pages 223 and 225 also shows the increase in volume of Q 3–2 at A_r 3–2 and the decrease in volume of Q 1 at A_r–1 as the maximum temperature of heating is reduced.

The temperature where $\frac{dt}{d\theta}$ is a maximum, or in other words, the peak of the critical point for all the maximum temperatures and rates of cooling, is recorded in the following table:

HELD 0 HOUR AT MAXIMUM TEMPERATURE.

Rate of cooling	Maximum temperature of heating. 1,100	1,000	900	800	
Furnace	615	620	620	630	A_r 3–2
	590	590	580	590	A_r 1
Air	535	545	550	555	A_r 3–2
	510	500	500	Not present.	A_r 1

HELD 1 HOUR AT MAXIMUM TEMPERATURE.

Rate of cooling	Maximum temperature of heating. 1,100	1,000	900	800	
Furnace	620	620	645	625	A_r 3–2
	590	600	600	590	A_r 1
Air	540	545	550	560	A_r 3–2
	500	510	510	500	A_r 1

HELD 6 HOURS AT MAXIMUM TEMPERATURE.

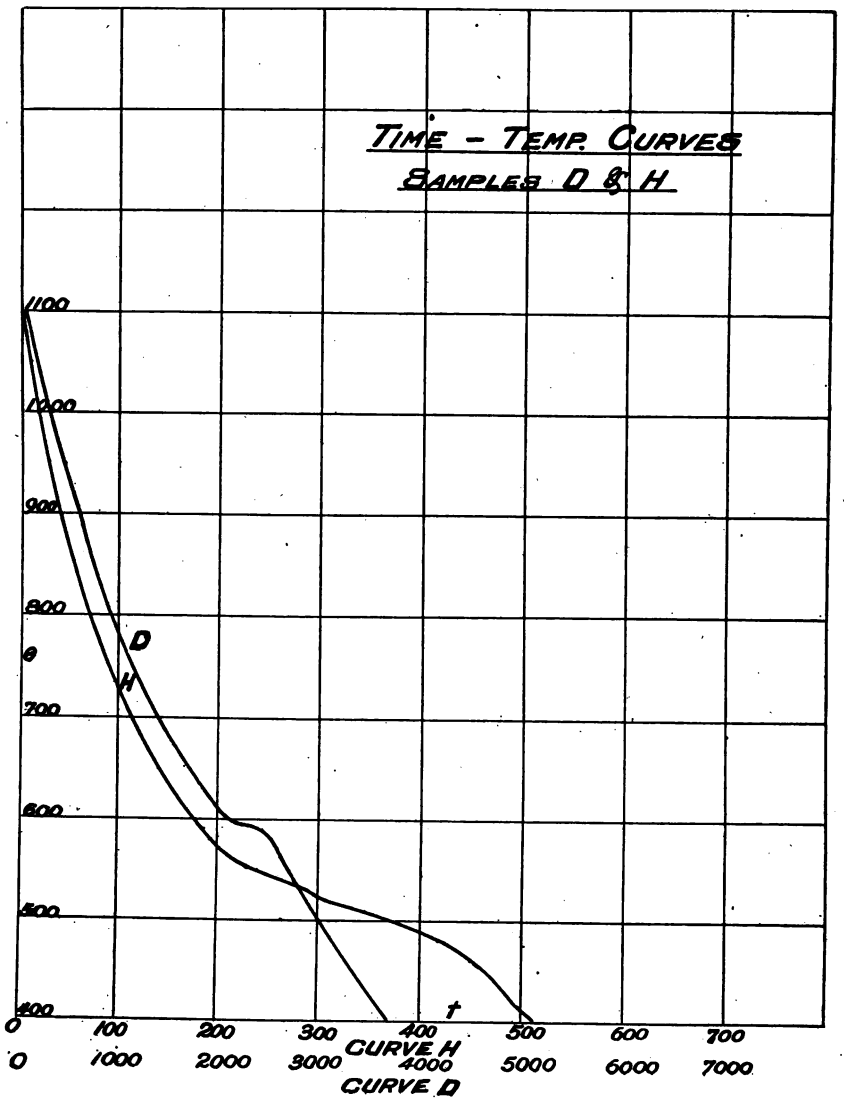
Rate of cooling	Maximum temperature of heating. 1,100	1,000	900	800	
Furnace	620	620	Curves	620	A_r 3–2
	590	590	failure.	590	A_r 1
Air	545	550	550	Curves	A_r 3–2
	500	510	510	failure.	A_r 1

An inspection of these results show—

(1) That A_r 3–2 occurs at a more elevated temperature the lower the maximum temperature of heating. This is true both of furnace and air-cooled specimens in the series which was not held at the maximum temperature.

(2) This phenomenon is not so noticeable in the series held at the maximum temperature of heating for six hours, although it is very distinct in the air-cooled series soaked one hour at the maximum temperature.

(3) In any series the lower or A_r 1 point is not influenced as to location by the maximum temperature of heating.


TIME - TEMP. CURVES
SAMPLES D & H
1100
1000
900
800
θ
700
600
500
400
D
H
t
0
100
200
300
400
500
600
700
0
1000
2000
3000
4000
5000
6000
7000
CURVE H
CURVE D

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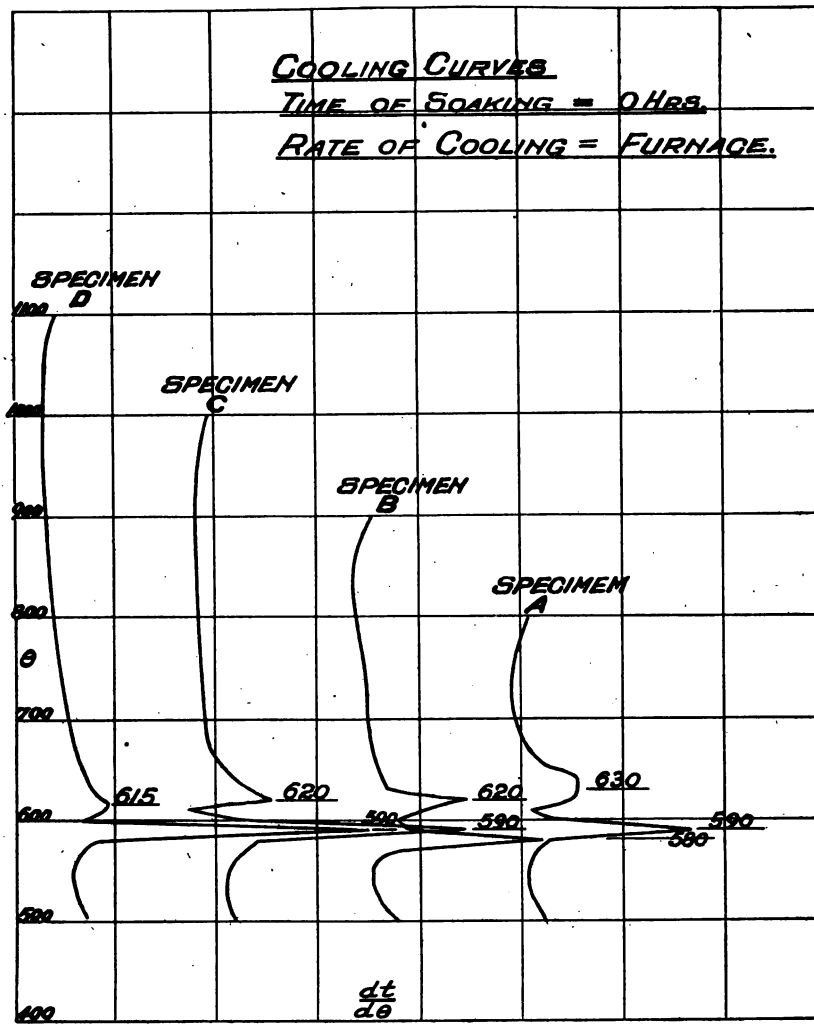
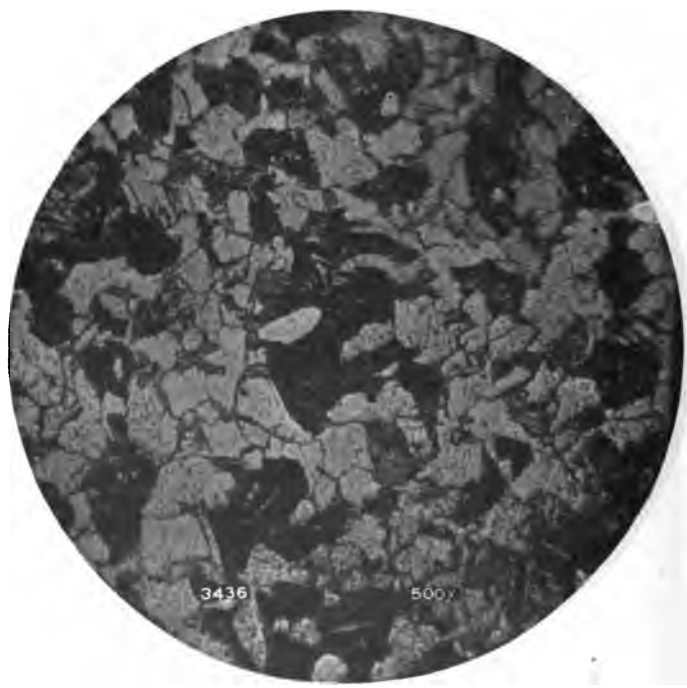

COOLING CURVES
TIME OF SOAKING = 0 HRS.
RATE OF COOLING = FURNACE.
SPECIMEN D
SPECIMEN C
SPECIMEN B
SPECIMEM A
1100
900
800
θ
700
600
500
400
615
620
620
630
590
590
590
dt/dθ

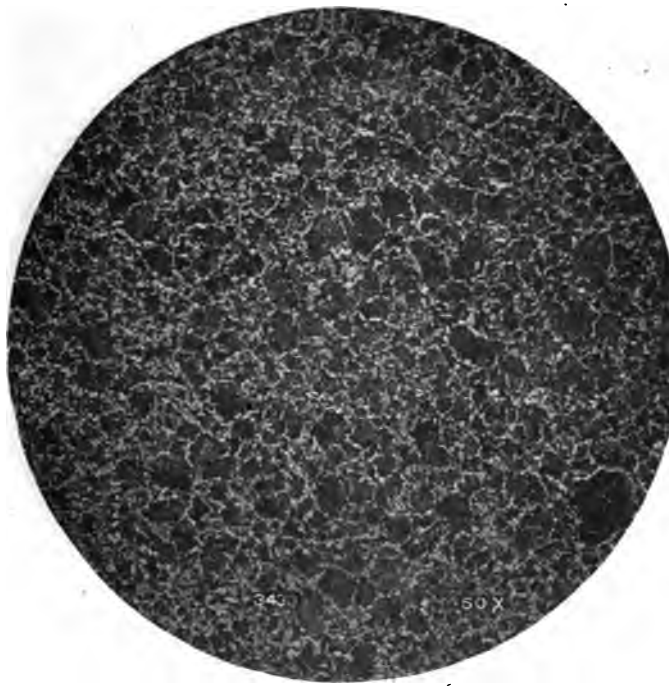
Specimen A. 800° C. Furnace cooled. 50 X.

Specimen A. 800° C. Furnace cooled. 500 X.

Specimen B. 900° C. Furnace cooled. 50 X.

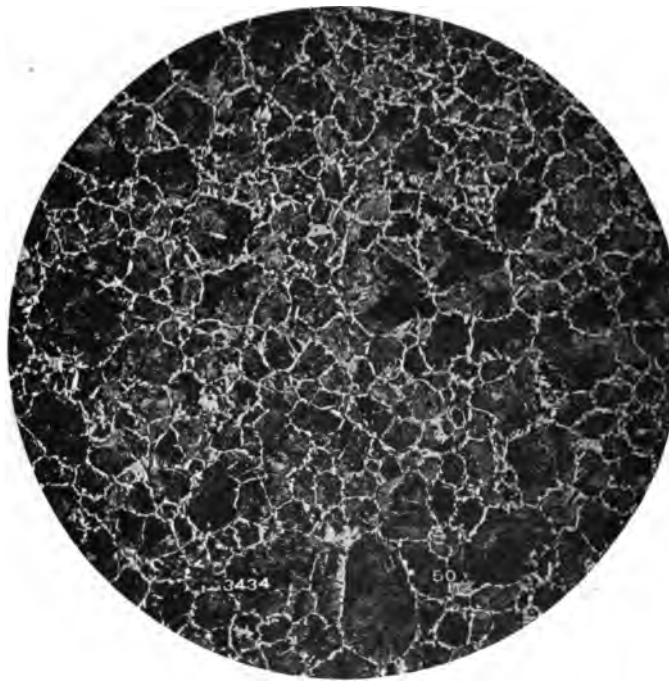


Specimen B. 900° C. Furnace cooled. 500 X.



Specimen C. 1,000° C. Furnace cooled. 50 X.

Specimen C. 1,000° C. Furnace cooled. 500 X.



Specimen D. 1,100° C. Furnace cooled. 50 X.

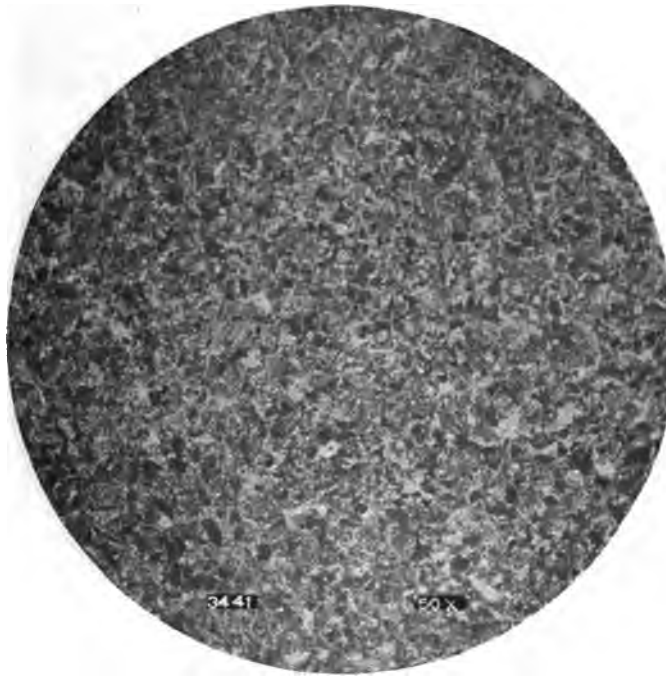
Specimen D. 1,110° C. Furnace cooled. 500 X.

Specimen E. 800° C. Air cooled. 50 X.

Specimen E. 800° C. Air cooled. 500 X.

Specimen F. 900° C. Air cooled. 50 X.

Specimen F. 900° C. Air cooled. 500 X.



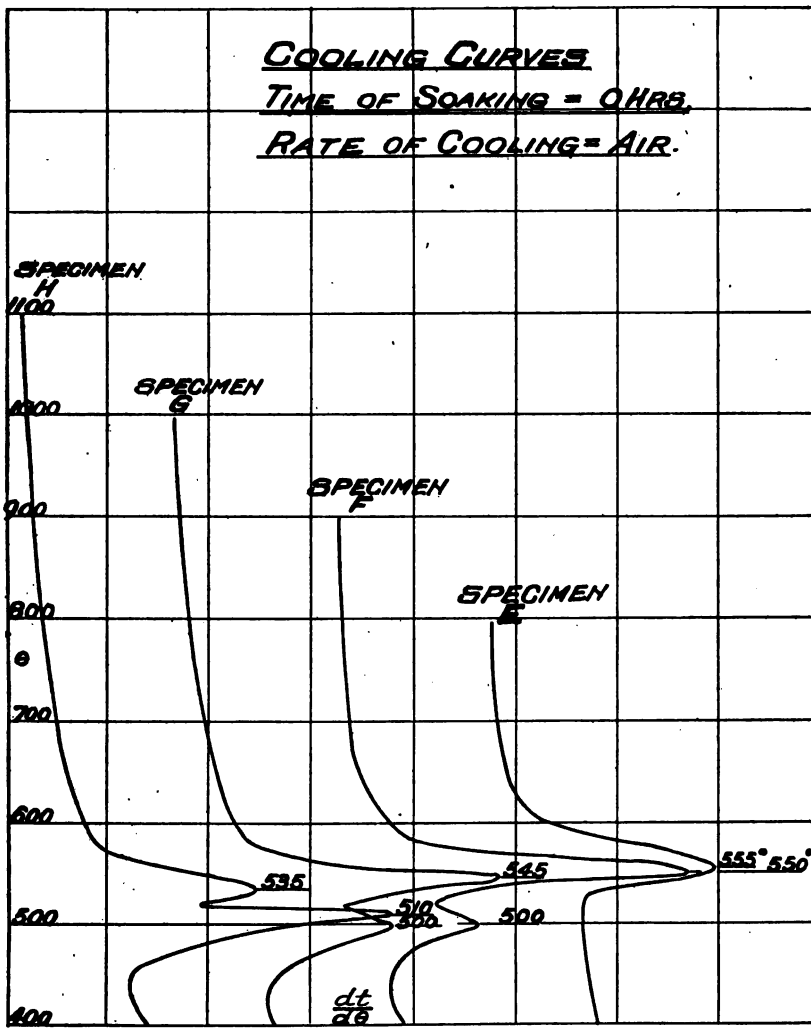
Specimen G. 1,000° C. Air cooled. 50 X.

Specimen G. 1,000° C. Air cooled. 500 X.

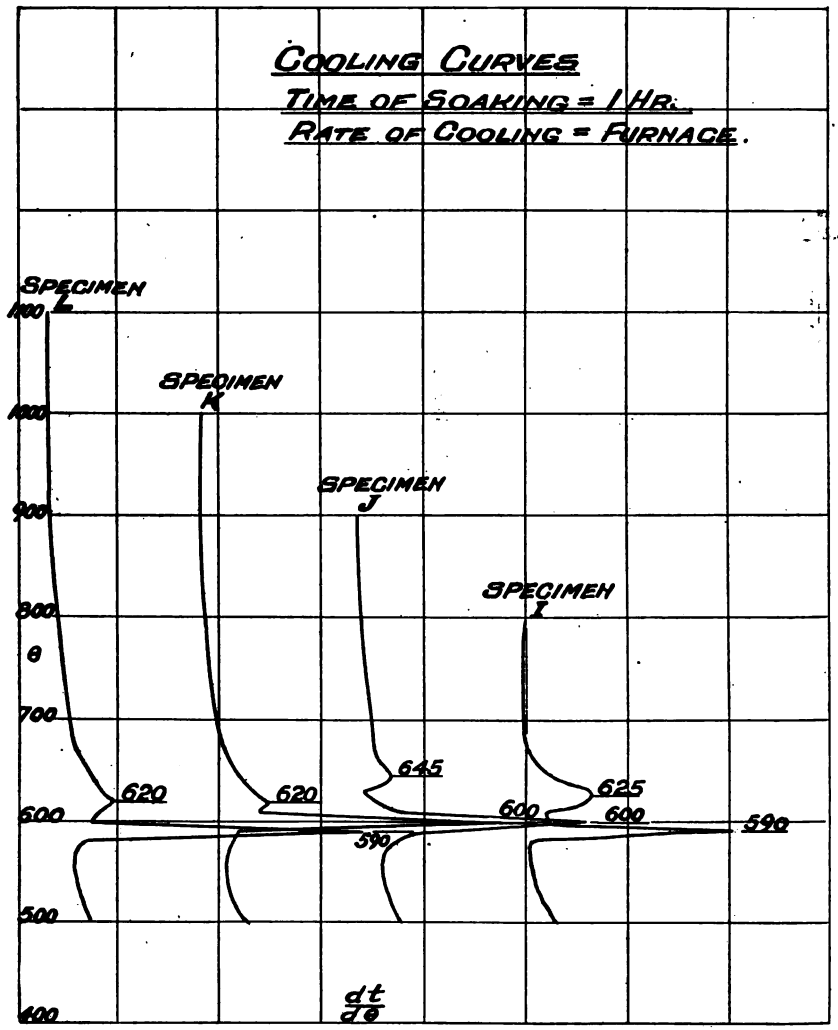
Specimen H. 1,100° C. Air cooled. 50 X.

Specimen H. 1,100° C. Air cooled. 500 X.

All specimens shown on this page were heated to, but not held at, the final temperature shown under each micrograph, then furnace cooled.



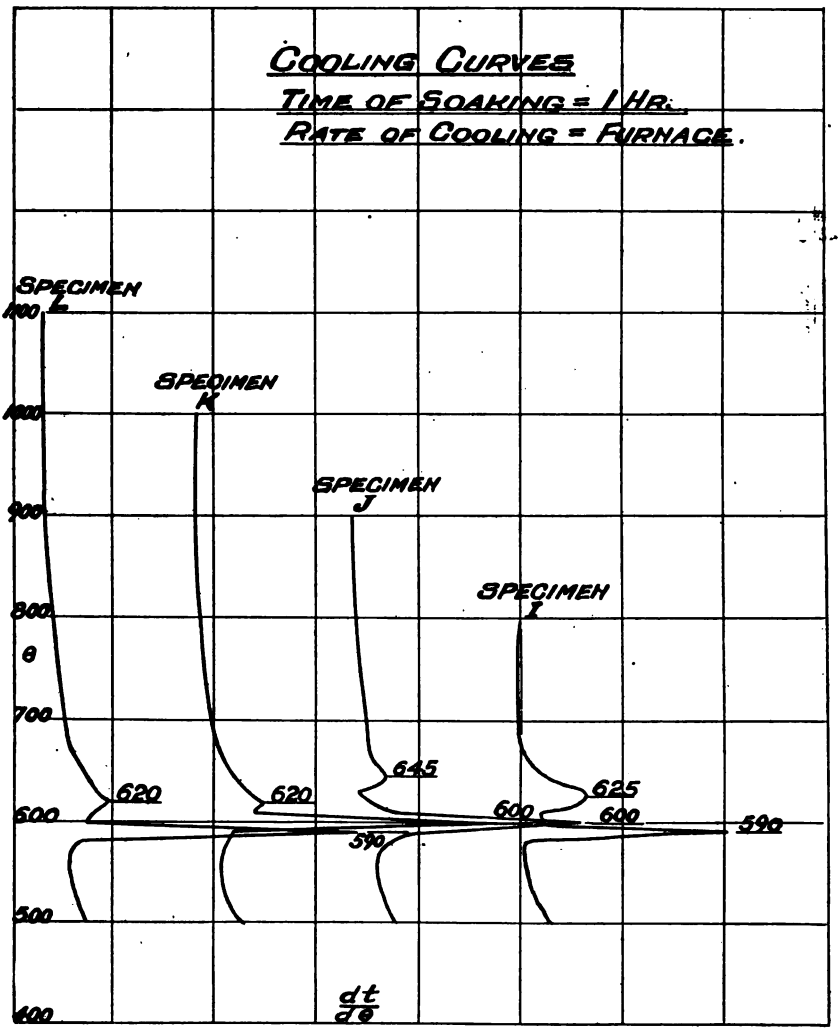
All specimens shown on this page were heated to but not held at the final temperature shown under each micrograph; air cooled.



Specimen I. 800° C., 1 hour. Furnace cooled. 50 X.

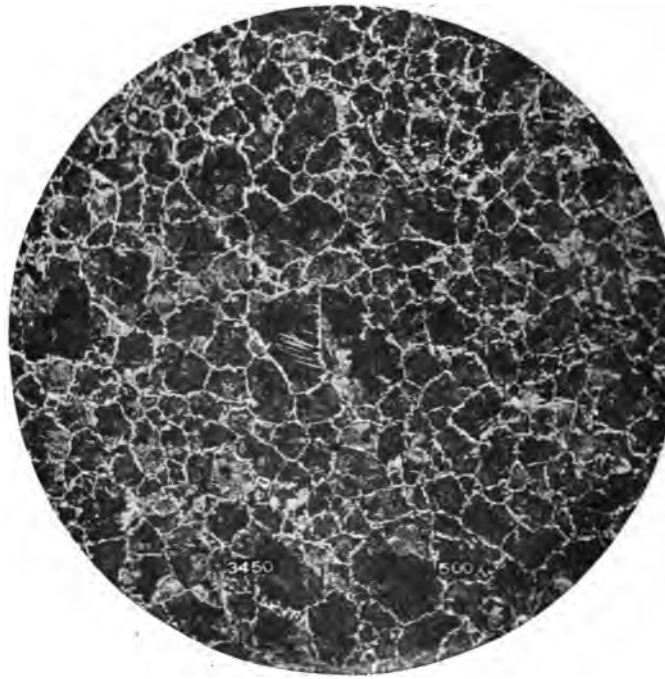
Specimen I. 800° C., 1 hour. Furnace cooled. 500 X.

All specimens shown on this page were heated to but not held at the final temperature shown under each micrograph; air cooled.



Specimen I. 800° C., 1 hour. Furnace cooled. 50 X.

Specimen I. 800° C., 1 hour. Furnace cooled. 500 X.



Specimen L. 1,100° C., 1 hour. Furnace cooled. 50 X.

Specimen L. 1,100 C., 1 hour. Furnace cooled. 500 X.

Specimen M. 800° C., 1 hour. Air cooled. 50 X.

Specimen M. 800° C., 1 hour. Air cooled. 500 X.

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Specimen N. 900° C., 1 hour. Air cooled. 50 X.

Specimen N. 900° C., 1 hour. Air cooled. 500 X.

Specimen O. 1,000° C., 1 hour. Air cooled. 50 X.

Specimen O. 1,000° C., 1 hour. Air cooled. 500 X.

Specimen N. 900° C., 1 hour. Air cooled. 50 X.

Specimen N. 900° C., 1 hour. Air cooled. 500 X.

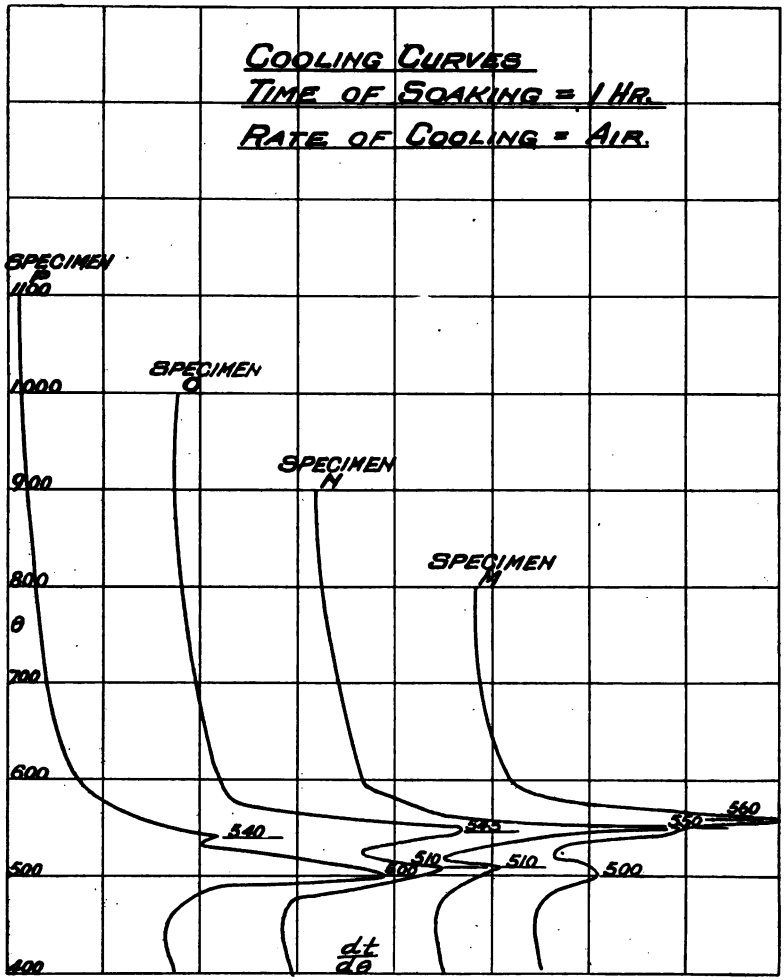
Specimen O. 1,000° C., 1 hour. Air cooled. 50 X.

Specimen O. 1,000° C., 1 hour. Air cooled. 500 X.

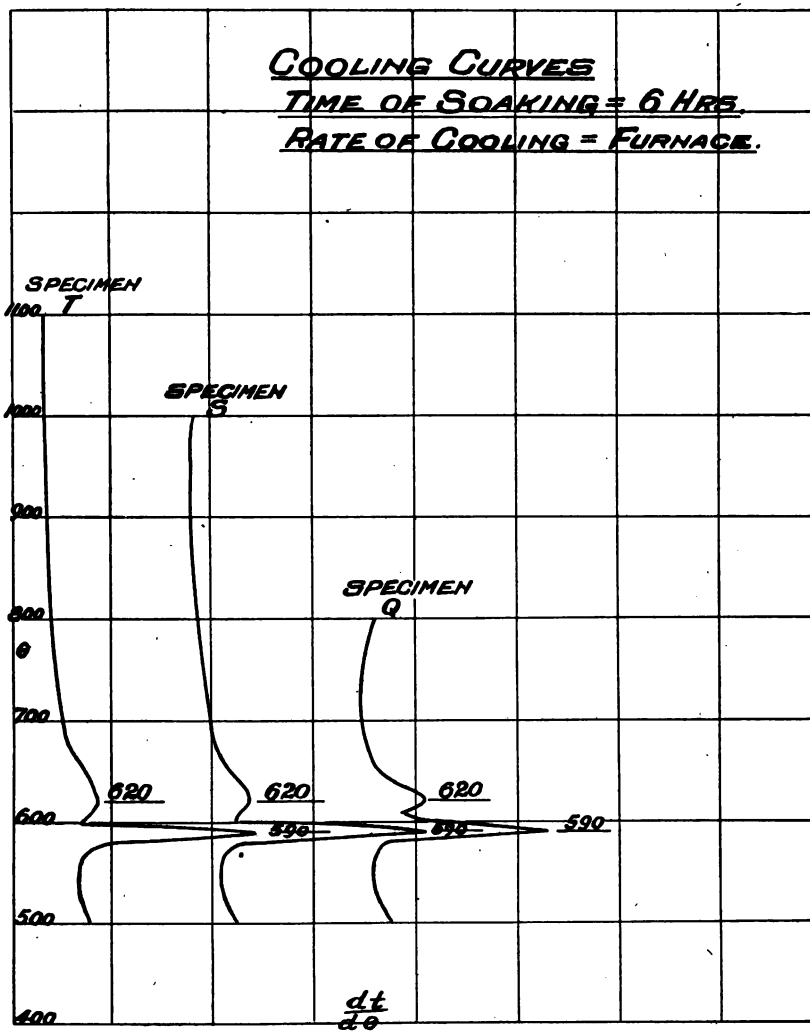
Specimen P. 1,100° C., 1 hour. Air cooled. 50 X.

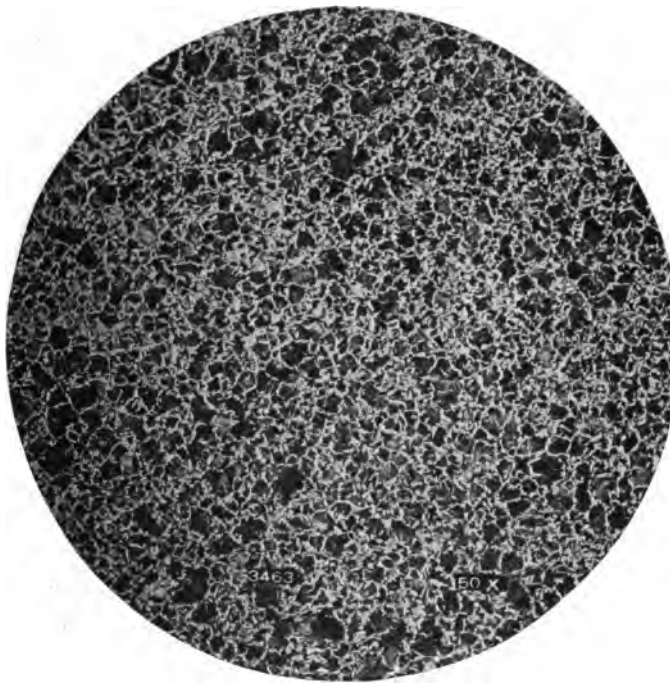
Specimen P. 1,100° C., 1 hour. Air cooled. 500 X.

All specimens shown on this page were held one hour at the final temperature shown under each micrograph, and then furnace cooled.

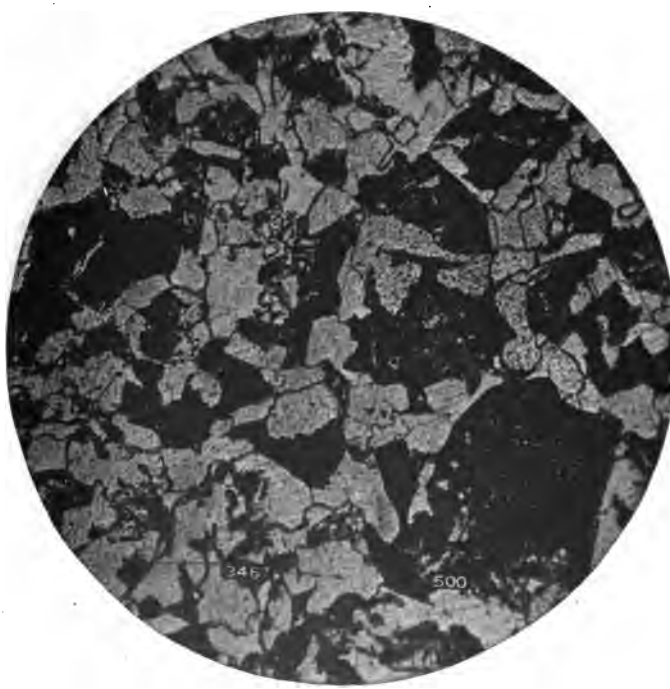


All specimens shown on this page were held one hour at the final temperature shown under each micrograph, and then air cooled.

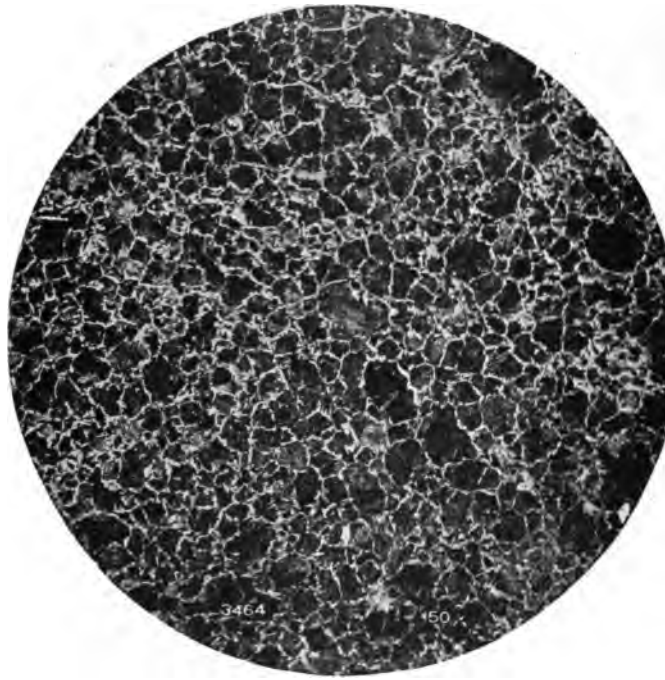




Specimen Q. 800° C., 6 hours. Furnace cooled. 50 X.

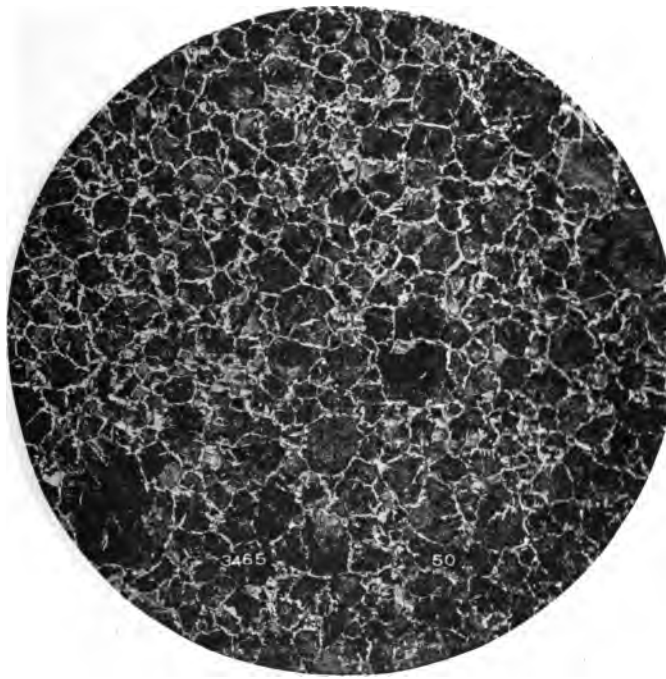


Specimen Q. 800° C., 6 hours. Furnace cooled. 500 X.



Specimen R. 900° C., 6 hours. Furnace cooled. 50 X.

Specimen R. 900° C., 6 hours. Furnace cooled. 500 X.

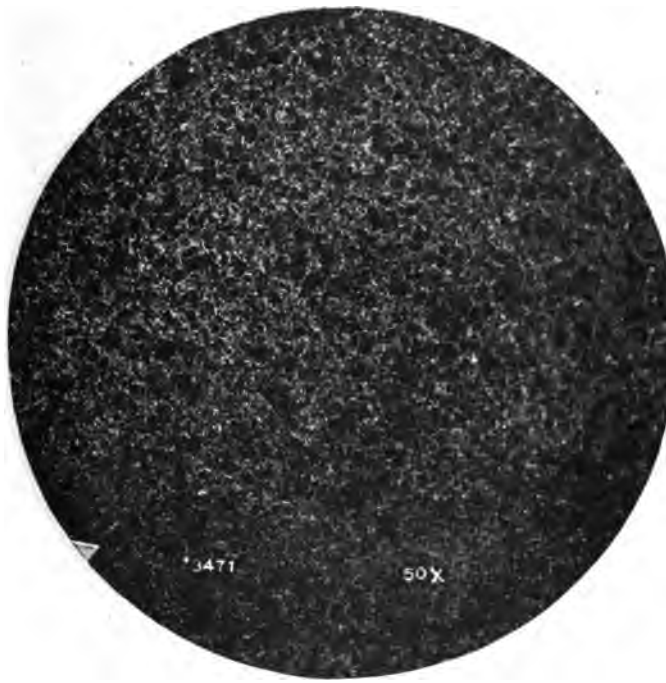


Specimen S. 1,000° C., 6 hours. Furnace cooled. 50 X.

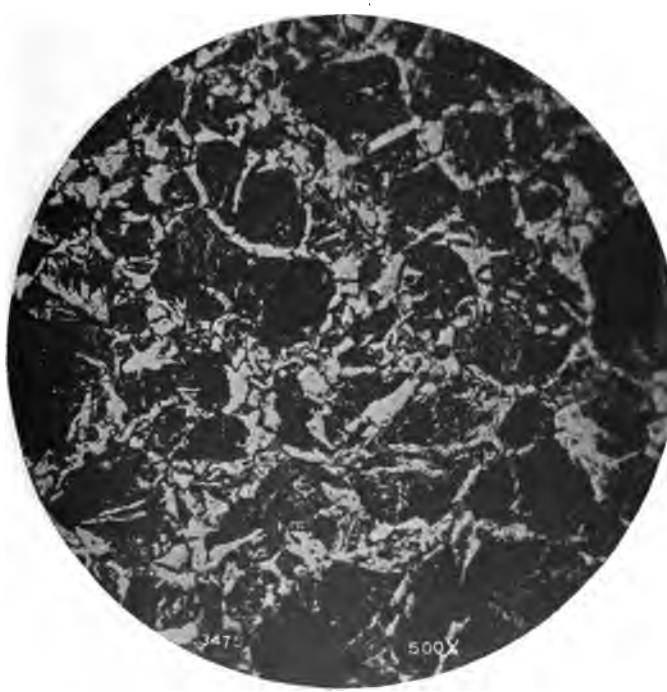
Specimen S. 1,000° C., 6 hours. Furnace cooled. 500 X.

Specimen T. 1,100° C., 6 hours. Furnace cooled. 50 X.

Specimen T. 1,100° C., 6 hours. Furnace cooled. 500 X.



Specimen U. 800° C., 6 hours. Air cooled. 50 X.



Specimen U. 800° C., 6 hours. Air cooled. 500 X.

Specimen V. 900° C., 6 hours. Air cooled. 50 X.

Specimen V. 900° C., 6 hours. Air cooled. 500 X.

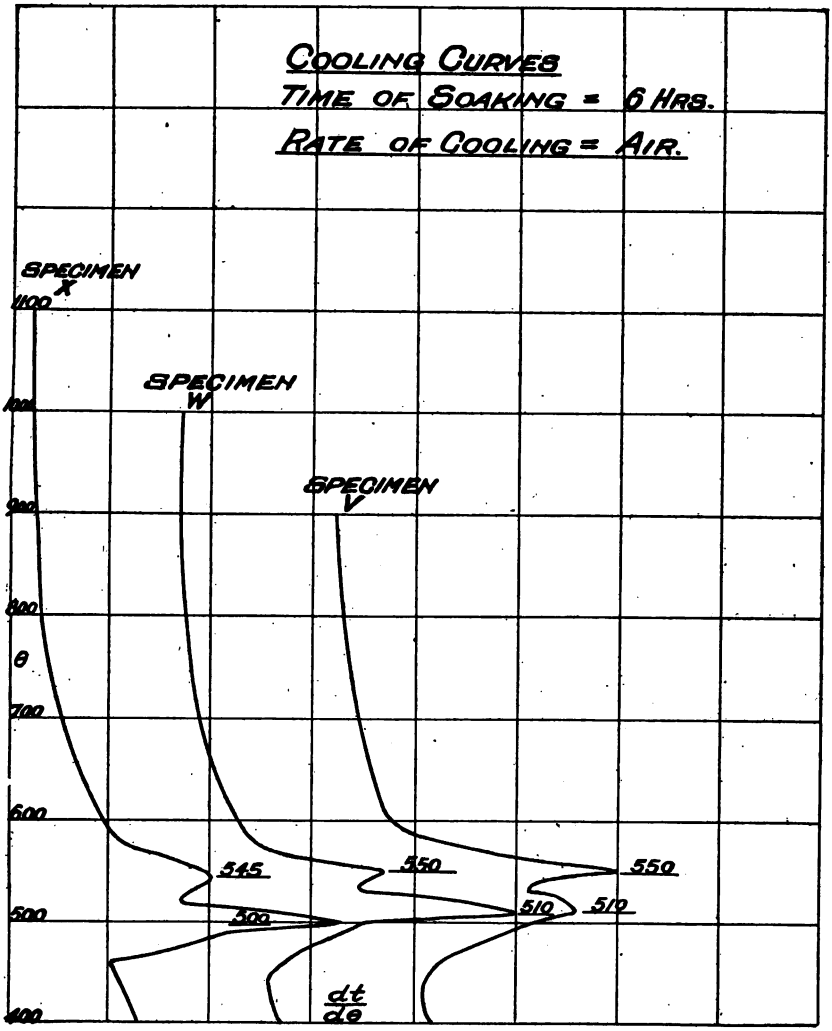
Specimen W. 1,000° C., 6 hours. Air cooled. 50 X.

Specimen W. 1,000° C., 6 hours. Air cooled. 500 X.

Specimen X. 1,100° C., 6 hours. Air cooled. 50 X.

Specimen X. 1,100° C., 6 hours. Air cooled. 500 X.

All specimens shown on this page were held six hours at the final temperature shown under each micrograph, and then furnace cooled.



SUPPLEMENTARY NOTES ON THE TRIANGULATED STRUCTURE IN CERTAIN NICKEL STEEL.

OBJECT.

The object of this investigation was to determine the physical properties associated with the triangulation of constituents brought about by certain treatments, the nature of which have been previously ascertained. It is of interest to note that the triangular structure referred to above is very frequently encountered in nickel steels, and experimental data thus far obtained indicates that its development is intimately associated with too high a hardening temperature.

CONCLUSIONS.

The effect of the triangulation of constituents is to give rise to an abnormally low proportional, or elastic limit, whereas the yield point may be relatively high. It was observed, for example, that furnace cooling from a given temperature gave a better value for the elastic limit and Charpy strength than air cooling from the same temperature. In other words, for a composition such as used in these experiments, namely, 0.34 per cent carbon, 3.50 per cent nickel, slow cooling gave better physical qualities than a more rapid rate. This seems in direct contradiction to all present generalizations, but it is to be borne in mind that the more rapid rate of cooling from above the critical point gave rise to a structure which might be styled "microscopic ingotism," and which is not removed by tempering.

Great care should be exercised in the treatment of all steels which readily yield the triangulated structure (distinct from martensite). The hardening temperature should be kept as low as possible, and the rate of cooling either slower or faster than the critical rate which gives triangulation. For a large forging this might mean quenching in water instead of in oil, if oil quenching gave the critical rate of cooling

EXPERIMENTAL.

The analysis of the stock used was as follows:

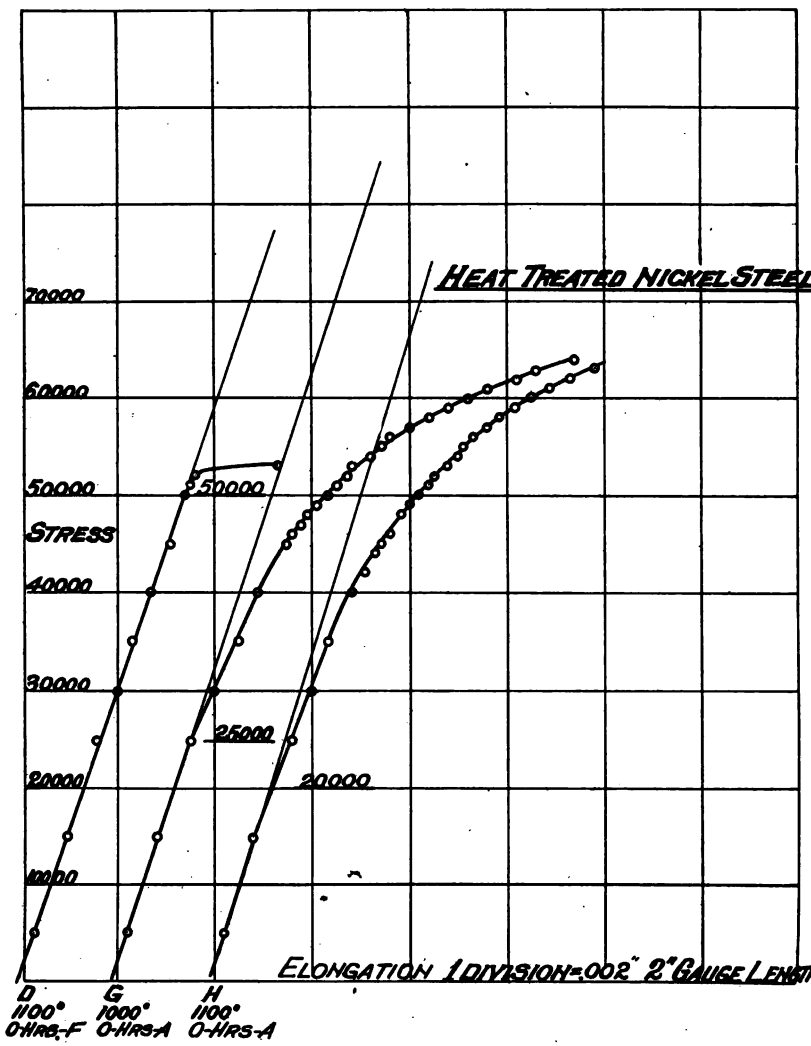
	Per cent.
C	0.34
Mn	.56
Si	.15
S	.031
P	.034
Ni	3.46
Cr	.18

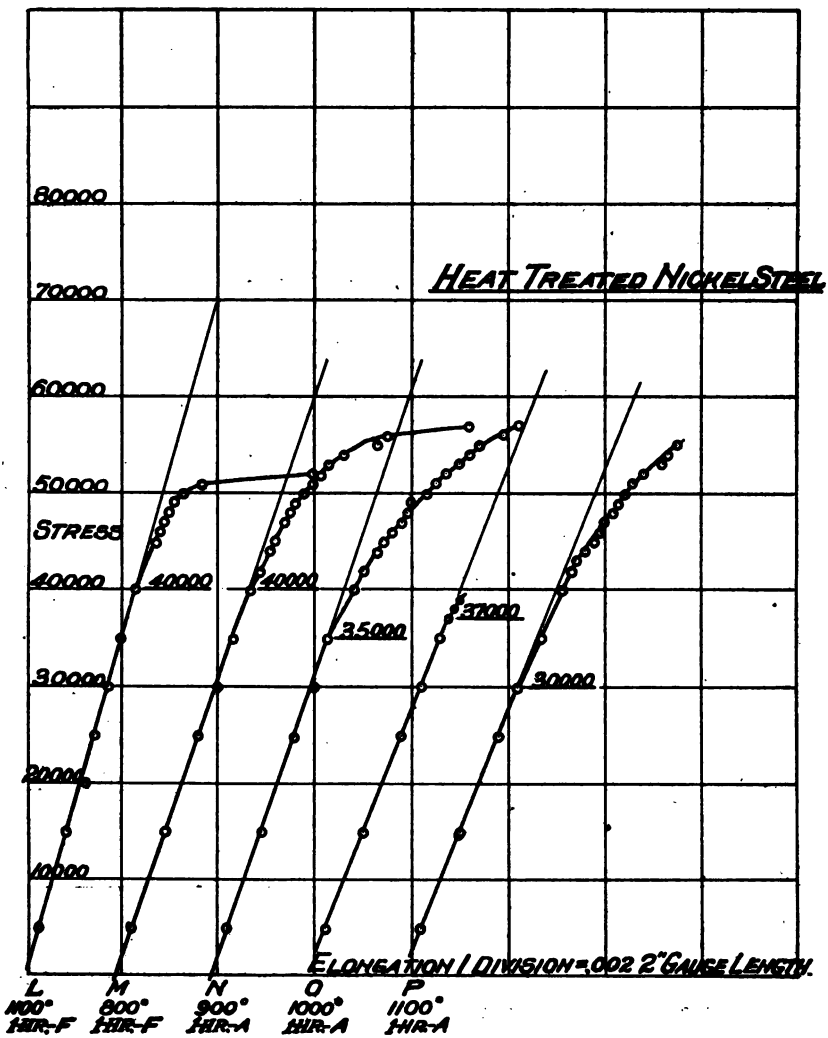
The steel used was in the form of 1 inch round bar stock, and the specimens treated were 8 inches in length. All heating was done in an electric muffle furnace, and the temperatures measured with a platinum couple and a potentiometer.

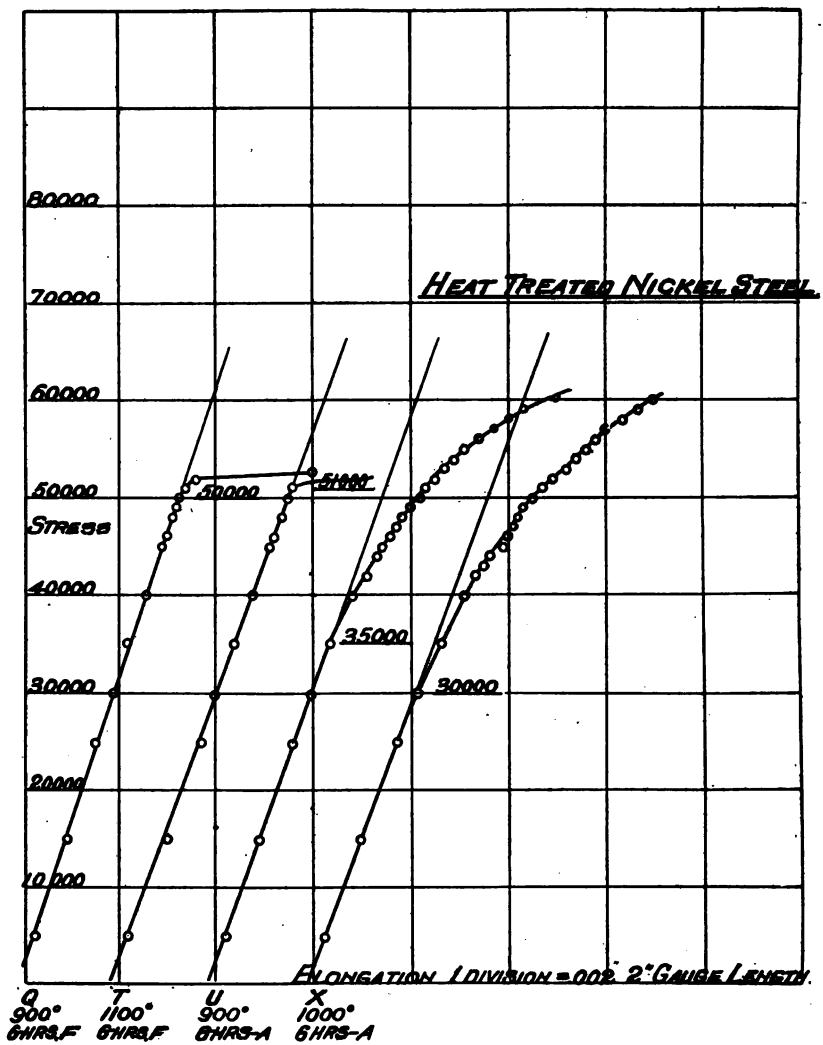
After treatment, one tensile and two Charpy bars were taken from each piece. The end of the tensile specimen was reserved for microscopic examination.

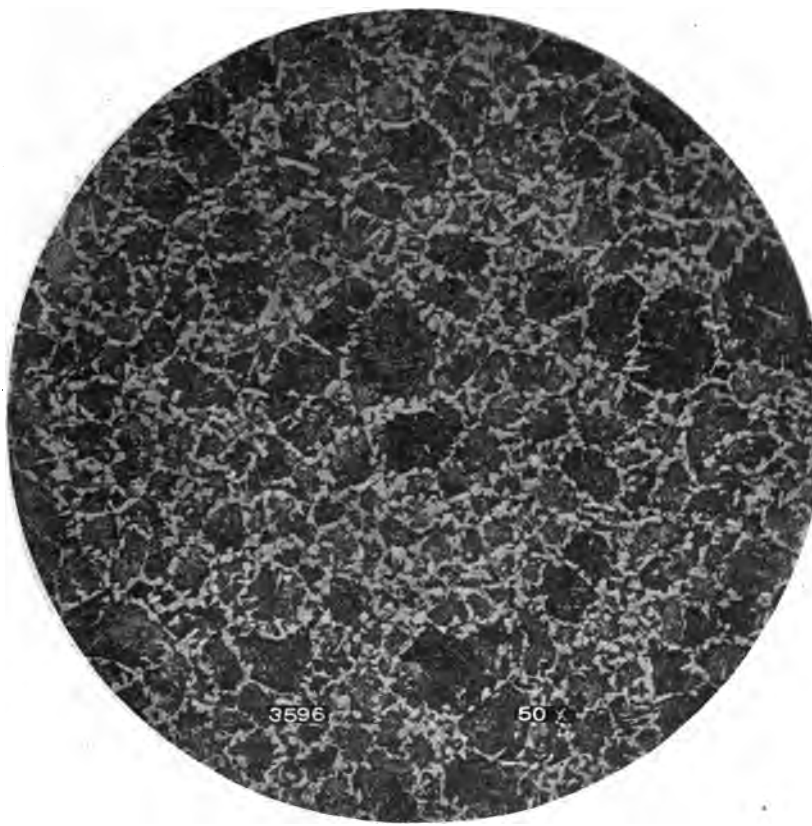
The following table gives the results of the physical tests. The stress-strain diagrams follow the table.

Marks.	Treatment.	Elastic limit—proportionality limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness (number).	Charpy test (foot-pounds per square inch).
10 D.....	1,100, 0 hour, furnace.....	50,000	94,000	25.0	51.9	179	247
10 G.....	1,000, 0 hour, air.....	25,000	101,500	21.5	51.9	197	213
10 H.....	1,100, 0 hour, air.....	20,000	100,500	22.0	51.9	197	223
10 L.....	1,100, 1 hour, furnace.....	40,000	95,500	24.5	51.9	183	232
10 M.....	800, 1 hour, furnace.....	40,000	98,500	24.5	57.2	187	325
10 N.....	900, 1 hour, air.....	35,000	102,000	22.5	54.6	192	278
10 O.....	1,000, 1 hour, air.....	37,000	101,000	21.5	51.9	197	218
10 P.....	1,100, 1 hour, air.....	30,000	98,500	20.5	49.1	197	198
10 Q.....	900, 6 hours, furnace.....	50,000	94,000	24.5	51.9	175	270
10 T.....	1,100, 6 hours, furnace.....	51,000	96,000	23.5	51.9	187	217
10 U.....	900, 6 hours, air.....	35,000	100,000	21.5	51.9	192	196
10 X.....	1,000, 6 hours, air.....	30,000	98,500	20.0	49.1	197	207


HEAT TREATED NICKEL STEEL
70000
60000
50000
STRESS
40000
30000
20000
10000
50000
25000
20000
ELONGATION 1 DIVISION=.002" 2" GAUGE LENGTH
D
1100°
0-HRS.-F
G
1000°
0-HRS-A
H
1100°
0-HRS-A


HEAT TREATED NICKEL STEEL
80000
70000
60000
50000
STRESS
40000
30000
20000
10000
40000
40000
35000
37000
30000
ELONGATION 1 DIVISION = .002 2" GAUGE LENGTH
L
1100° HR-F
M
800° HR-F
N
900° HR-A
O
1000° HR-A
P
1100° HR-A


HEAT TREATED NICKEL STEEL.
80000
70000
60000
50000
STRESS
40000
30000
20000
10000
50000
51000
35000
30000
ELONGATION 1 DIVISION = .002 2" GAUGE LENGTH.
Q
900°
6 HRS. F
T
1100°
6 HRS. F
U
900°
6 HRS-A
X
1000°
6 HRS-A



MICROGRAPH NO. 3596. 50 X.

Heat treatment—1,100° C., 0 hours; furnace. Sorbite with excess ferrite.

231-1

MICROGRAPH NO. 3597. 500 X.

High power on same field as Micrograph No. 3596.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 D.....	50,000	94,000	25.0	51.9	179	247

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
10 G.....	25,000	101,500	*Per cent.* 21.5	*Per cent.* 51.9	197	213

MICROGRAPH NO. 3594. 50 X.

1,000° C., 0 hours, air. Decided triangulation with many dark grains.

MICROGRAPH NO. 3595. 500 X.

High power on same field as Micrograph No. 3594.

MICROGRAPH NO. 3598. 50 X.

Heat treatment—1,100° C., 0 hours, air. Decided triangulation.

233-1

MICROGRAPH NO. 3599. 500 X.

High power on same field as Micrograph No. 3598.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 H.....	20,000	100,500	22.0	51.9	197	223

NOTES ON SPECIMENS HELD 0 TIME AT MAXIMUM TEMPERATURES.

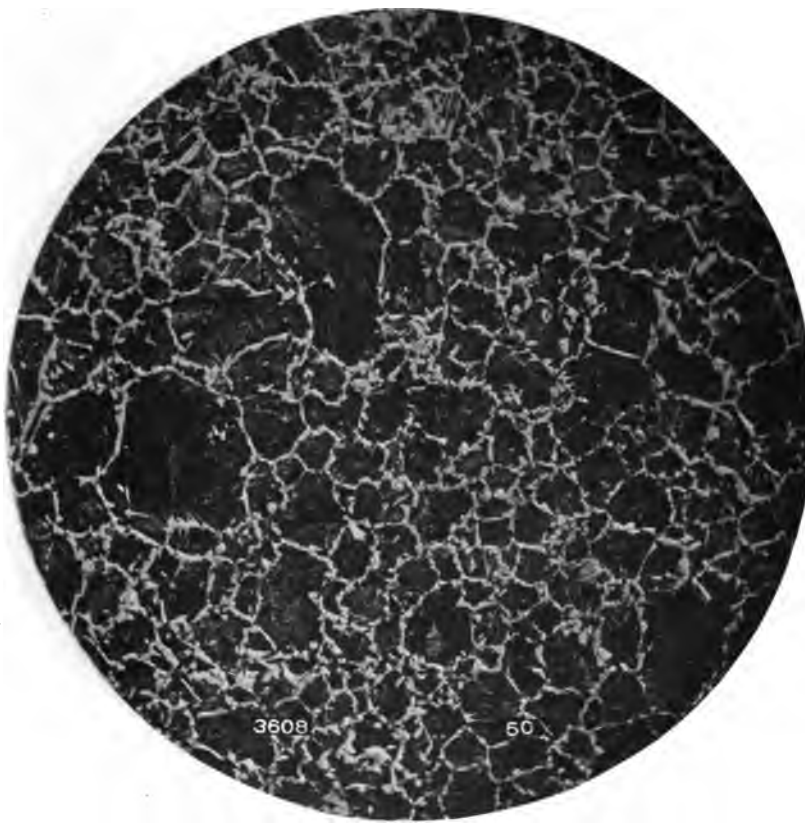
The specimens in which the triangular structure appears have a very low elastic limit. The Charpy strength is also inferior to that of the furnace-cooled sample.

Sample 10 H, which has more of the triangular constituent than 10 G, has a lower elastic limit by 5,000 pounds.

The Brinell hardness of the air-cooled specimens is greater than the furnace-cooled pieces.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 L	40,000	95,500	24.5	51.9	183	232



MICROGRAPH NO. 3608. 50 X.

Heat treatment—1,100° C., 1 hour, furnace. Sorbitic with network of excess ferrite.

234-1.

MICROGRAPH NO. 3609. 500 X.

High power on same field as Micrograph No. 3608. Structure shows tendency toward triangulation.

MICROGRAPH NO. 3600. 50 X.

Heat treatment—800° C., 1 hour, furnace. Fine sorbitic structure.

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MICROGRAPH NO. 3601. 500 X.

High power on same field as Micrograph No. 3600.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 M.....	40,000	98,500	24.5	57.2	187	325

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 N.....	35,000	102,000	22.5	54.6	192	278

MICROGRAPH NO. 3602. 50 X.

Heat treatment—900° C., 1 hour, air. Triangulation present but not marked.

MICROGRAPH NO. 3603. 500 X.

High power on same field as Micrograph No. 3602.

MICROGRAPH NO. 3604. 50 X.

Heat treatment = 1,000° C., 1 hour, air. Triangulation, and many dark grains.

237-1

MICROGRAPH NO. 3605. 500 X.

High power on same field as Micrograph No. 3604.

237-2

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 O.....	37,000	101,000	21.5	51.9	197	218

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 P	30,000	98,500	20.5	49.1	197	198

NOTES ON SPECIMENS HELD ONE HOUR AT MAXIMUM TEMPERATURE.

Specimen 10 L has a much coarser structure than 10 M, as it was heated to 1,100°, whereas 10 M was heated only to 800°. The only great difference in physical properties to be observed occurs in the Charpy strength, the fine-grained specimen giving 325 and the coarse-grained one only 232.

Specimens 10 N, 10 O, and 10 P, heated for one hour at 900°, 1,000°, and 1,100°, respectively, show an increasing proportion of the triangular constituent as the temperature of heating is increased. The elastic limit does not decrease regularly but is 5,000 pounds less in the 1,100° specimen than in the 900° specimen. The Charpy strength does fall off consistently as the proportion of triangular structure increases, or, in other words, as the maximum temperature of heating is raised.

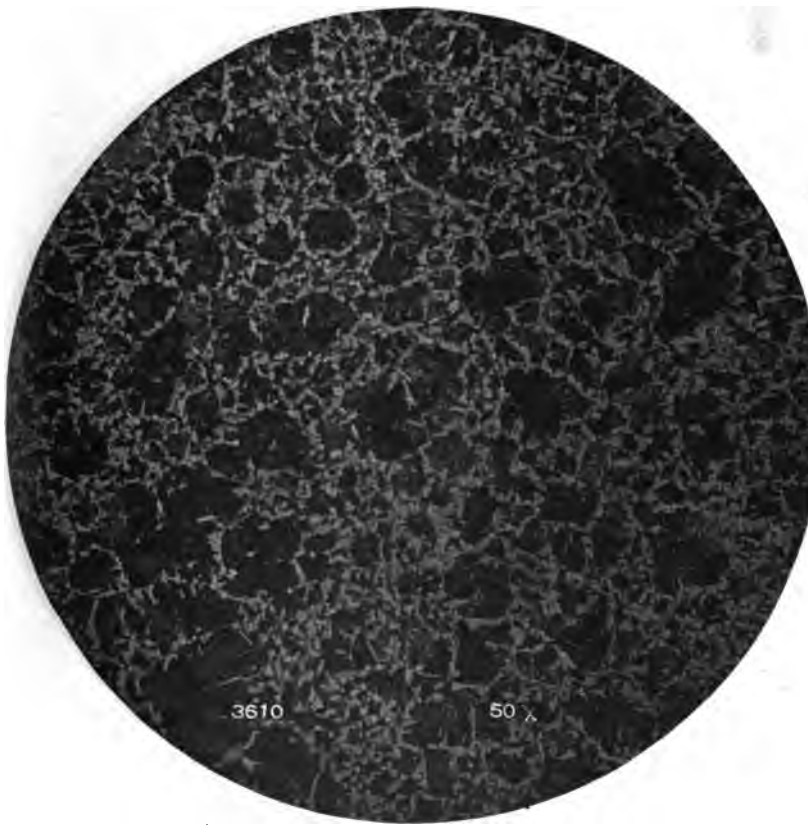
MICROGRAPH NO. 3606. 50 X.

Heat treatment—1,100° C., 1 hour, air. Decided triangulation.

MICROGRAPH NO. 3607. 500 X.

High power on same field as Micrograph No. 3606.

238-2



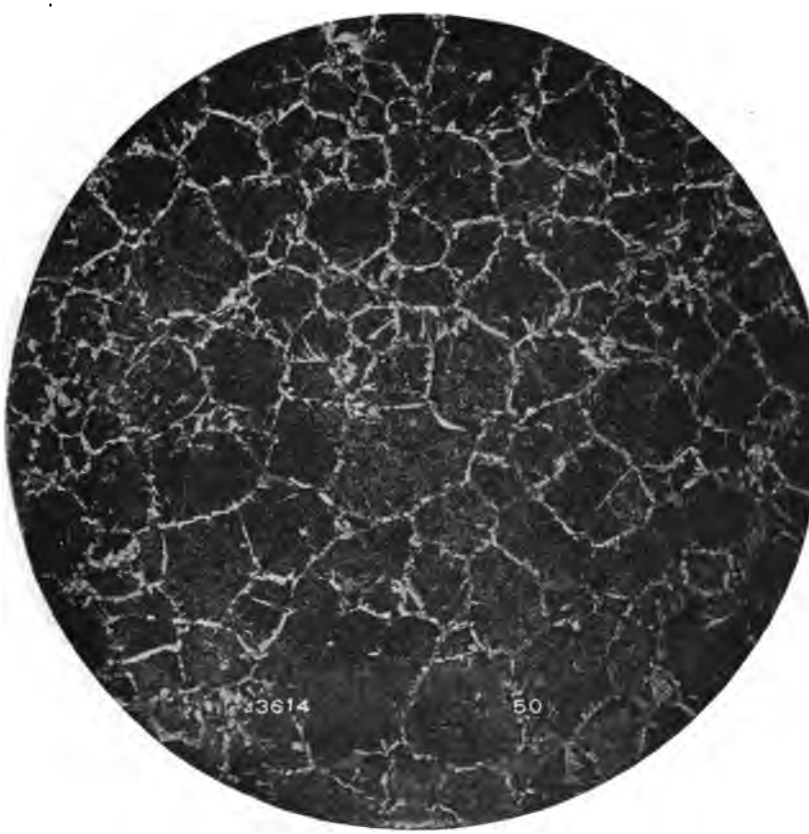
MICROGRAPH NO. 3610. 50 X.

Heat treatment = 900° C., 6 hours, furnace. Structure sorbitic with excess ferrite.

239-1

PHYSICAL TEST.

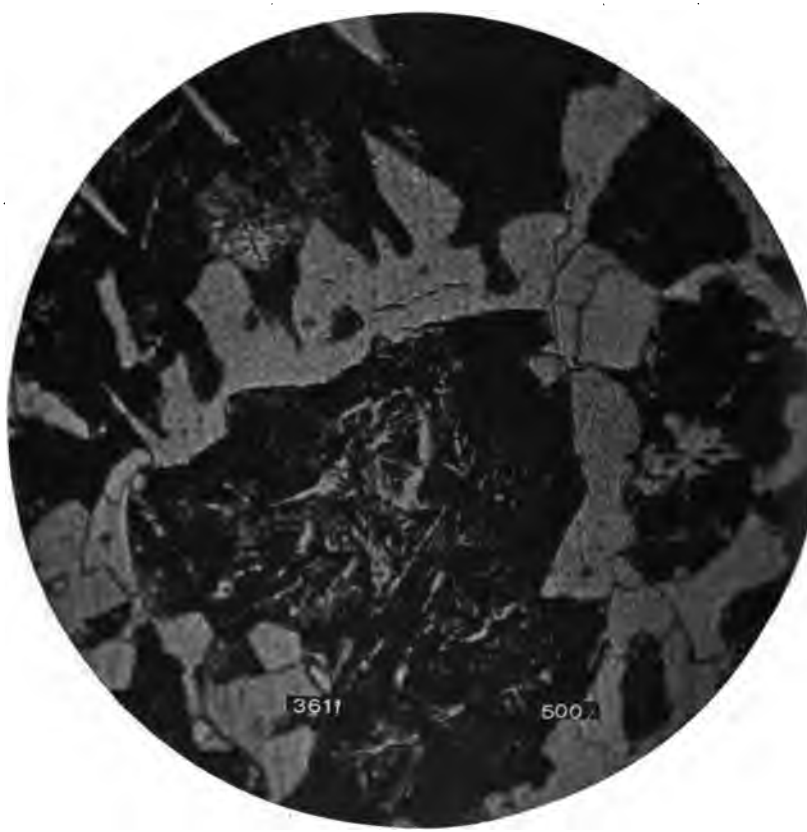
Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
10 T.....	51,000	96,000	*Per cent.* 23.5	*Per cent.* 51.9	187	217



MICROGRAPH NO. 3614. 50 X.

Heat treatment—1,100° C., 6 hours, furnace. Structure is sorbitic with network of free ferrite.

31082—18——27



MICROGRAPH NO. 3611. 500 X.

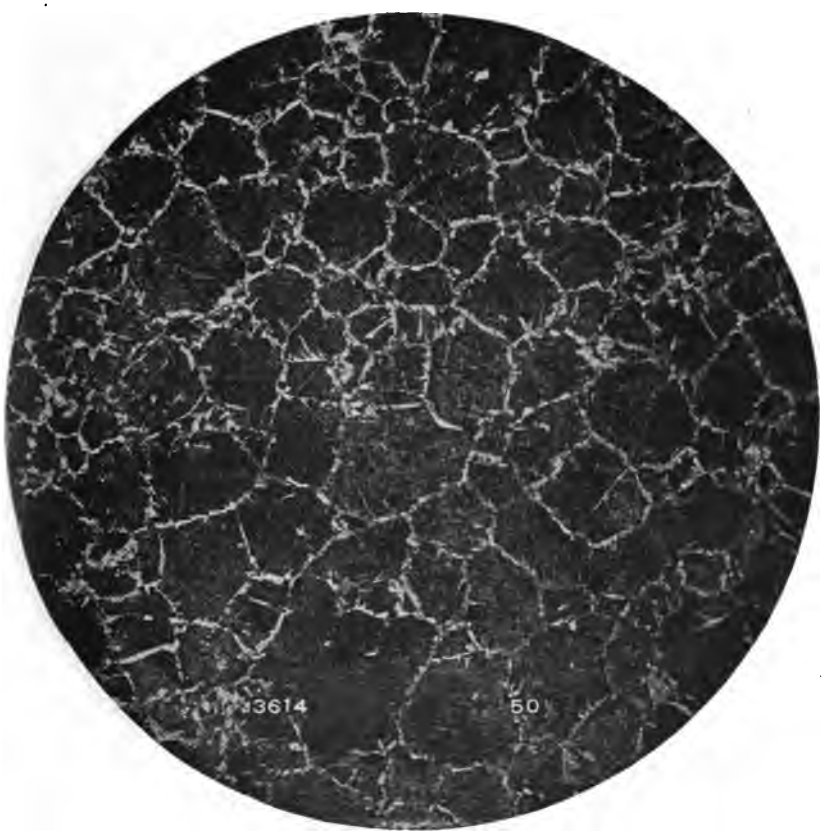
High power on same field as Micrograph No. 3610.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 Q	50,000	94,000	24.5	51.9	175	270

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 T.....	51,000	96,000	23.5	51.9	187	217



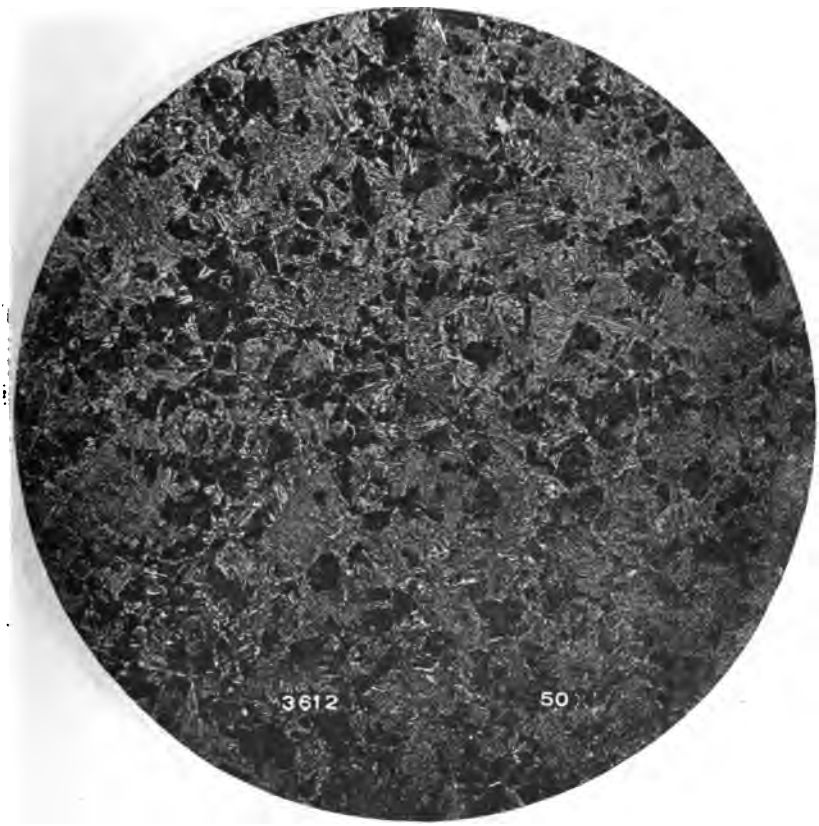
MICROGRAPH NO. 3614. 50 X.

Heat treatment—1,100° C., 6 hours, furnace. Structure is sorbitic with network of free ferrite.

31082—18——27

MICROGRAPH NO. 3615. 500 X.

High power on same field as Micrograph No. 3614.



MICROGRAPH NO. 3612. 50 X.

Heat treatment—900° C., 6 hours, air. Distinct triangulation with many dark grains.

241-1

MICROGRAPH NO. 3613. 500 X.

High power on same field as Micrograph No. 3612.

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
10 U	35,000	100,000	*Per cent.* 21.5	*Per cent.* 51.9	192	196

PHYSICAL TEST.

Marks.	Elastic limit.	Tensile strength.	Elongation.	Contraction.	Brinell.	Charpy.
			Per cent.	*Per cent.*		
10 Y	30,000	98,500	20.0	49.1	197	207

NOTES ON SPECIMENS HELD 6 HOURS AT MAXIMUM TEMPERATURE.

Specimens 10 Q and 10 T, heated to 900° and 1,100°, respectively, show little difference in the properties determined by the ordinary static test, whereas the Charpy results show that the fine-grained specimen is superior.

Specimens 10 U and 10 X show a decrease in the value of the elastic limit as the amount of triangulation increases. The air-cooled specimens, as in the other cases examined, had a value for the elastic limit which was less than that found in a furnace-cooled specimen having identical treatment in all other respects.

APPENDIX.

It has been pointed out previously that a critical composition existed at which the formation of the triangular structure was most readily produced. In support of this assumption the following experimental data is presented.

A crucible melt of 150 pounds was made in the foundry furnace and forged down to 1 inch round stock. The analysis of this stock is given below:

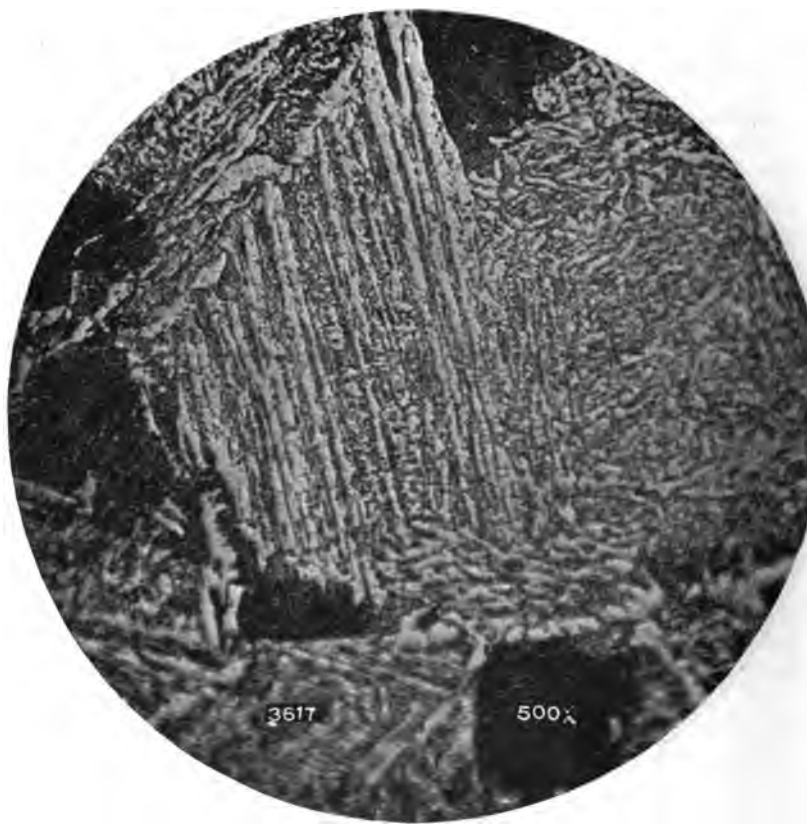
	Per Cent.		Per Cent.
C	0.54	S	.028
Mn	.51	P	.015
Si	.355	Ni	3.75

This material differs from that previously described in this report by having 20 points more carbon. There is not enough variation in the other elements concerned to explain the difference in physical properties observed.

MICROGRAPH NO. 3616. 50 X.

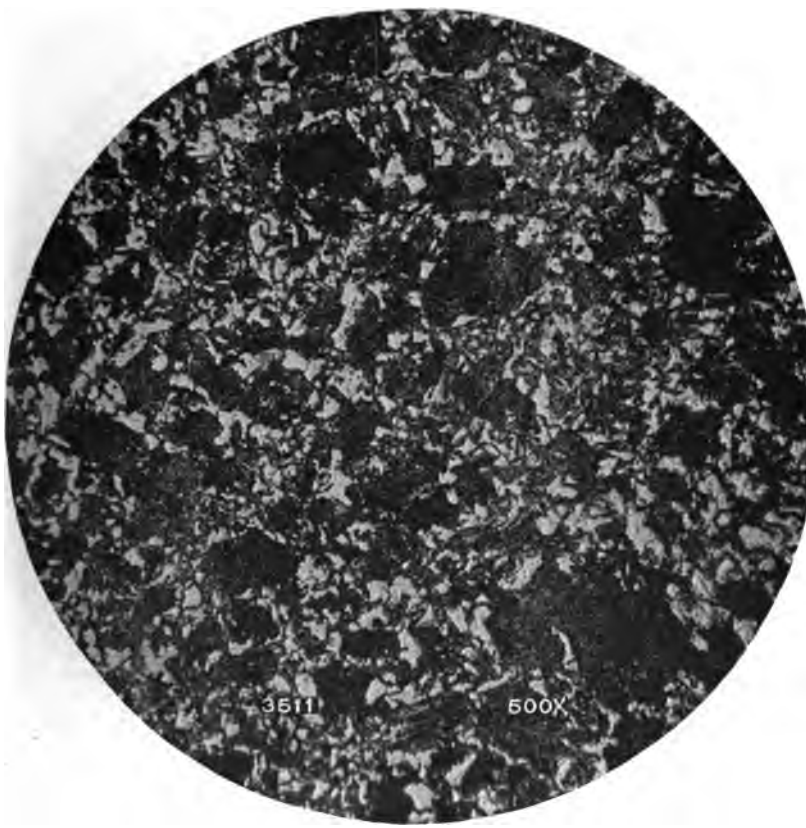
Heat treatment = 1,000° C., 6 hours, air cooled. Note distinct triangulation.

242-1



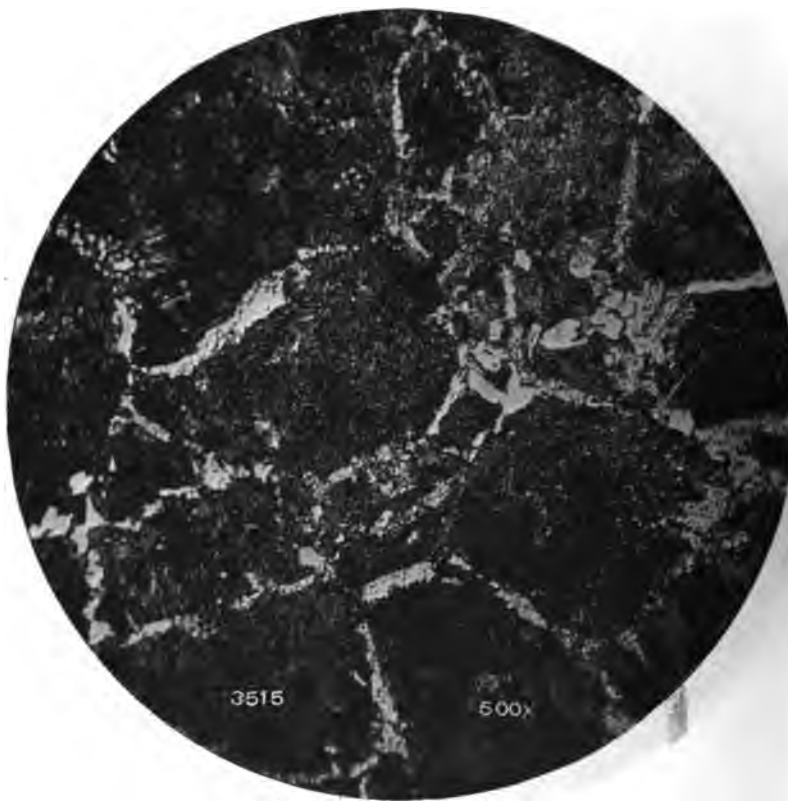
MICROGRAPH NO. 3617. 500 X.

High power on same field as Micrograph No. 3616.



MICROGRAPH NO. 3511. 500 X.

18 J. 800° C., 0 hours, air cooled. Sorbitic with excess ferrite.



MICROGRAPH NO. 3515. 500 X.

18 H. 1,100° C., 0 hours, air cooled. Sorbitic with traces of pearlite. There is no indication of the rejection of ferrite to the cleavage planes, or, in other words, triangulation is absent, whereas in a steel of otherwise similar composition but being lower in carbon by 20 points showed most marked triangulation after this treatment.

MICROGRAPH NO. 3582. 500 X.

18 E. 1,100° C., 6 hours, air cooled. Sorbitic with traces of pearlite. All the excess ferrite rejected to boundary lines. In the nickel steel containing 0.34 carbon, treatment similar to the above would have resulted in the rejection of the entire excess ferrite to the cleavage planes producing the triangular structure and the consequent reduction of the elastic limit.

MICROGRAPH NO. 3584. 500 X.

18 J. 1,100° C., 6 hours, furnace cooled. Pearlitic with excess ferrite.

243-4

The following table contains the significant data obtained on testing the specimens after various treatments:

Marks.	Proportional limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Charpy test (foot pounds per square inch).	Brinell hardness (number).
18 A. 1,100°, 0 hours, furnace	58,000	107,000	17.5	20.5	97.8	197
18 H. 1,100°, 0 hours, air	67,000	124,000	16.0	34.0	119.0	235
18 I. 1,000°, 0 hours, air	71,000	121,500	18.0	37.2	143.0	241
18 J. 800°, 0 hours, air	74,000	113,500	21.5	43.3	193.0	217
18 K. 1,100°, 1 hour, furnace	58,000	112,000	17.5	34.0	110.0	212
18 P. 1,100°, 1 hour, air	67,000	127,000	16.5	30.7	127.0	241
18 B. 1,000°, 1 hour, air	69,000	120,500	15.5	34.0	133.0	229
18 C. 900°, 1 hour, air	77,000	115,000	20.0	40.3	197.0	223
18 D. 800°, 1 hour, air	78,000	115,500	19.0	40.3	150.5	223
18 O. 1,100°, 6 hours, furnace	58,000	113,500	17.5	27.4	109.0	229
18 L. 800°, 6 hours, furnace	69,000	102,500	20.5	40.3	148.0	197
18 E. 1,100° 6 hours, air	66,000	125,500	15.0	30.7	107.0	241
18 F. 1,000°, 6 hour, air	70,000	119,500	17.5	40.3	169.0	229
18 G. 800°, 6 hours, air	79,000	111,000	20.5	40.3	187.0	223
18 N. 800° oil, dr. 400°, 15 minutes	162,000	197,000	12.0	43.3	110.0	389
18 M. 800° oil, dr. 400° for 30 minutes	155,000	188,500	13.0	46.2	123.0	389

Considering first tests 18 A, 18 H, 18 I, and 18 J, it is to be noted that the lower maximum temperature of heating the higher the elastic limit, and, furthermore, air cooling gives better physical properties than furnace cooling. The elevation of the elastic limit by increasing the rate of cooling is what normally would be expected.

The above observation can be repeated on the specimens held one hour at the maximum temperature, and also on those held six hours at the maximum temperature. Under no conditions of heating or rate of cooling was any tendency observed on the part of the excess ferrite to separate in the cleavage planes or, in other words, cause triangulation.

The following micrographs are introduced to show clearly why normal behavior was found in the composition, whereas in the 0.34 carbon the elastic limit was lowered by air cooling.

CHROME VANADIUM STEEL FOR ELEVATING SCREWS.

OBJECT.

The object of using chrome vanadium steel for the manufacture of elevating screws was to obtain the necessary static physical requirements of forged steel "D" and at the same time secure a high Charpy test.

The composition desired is shown below.

	Per cent.
Carbon	0.35–0.40
Vanadium	.20– .25
Chrome	1.00
Manganese, not less than	.50
Silicon	.15– .35

The actual composition obtained from heat 5,057 was as follows:

	Per cent.
Carbon	0.41
Vanadium	.27
Chrome	1.10
Manganese	.52
Silicon	.180
Sulphur	.050
Phosphorus	.021

The following table shows the treatments given the forging made from the chrome vanadium ingot and physical properties resulting:

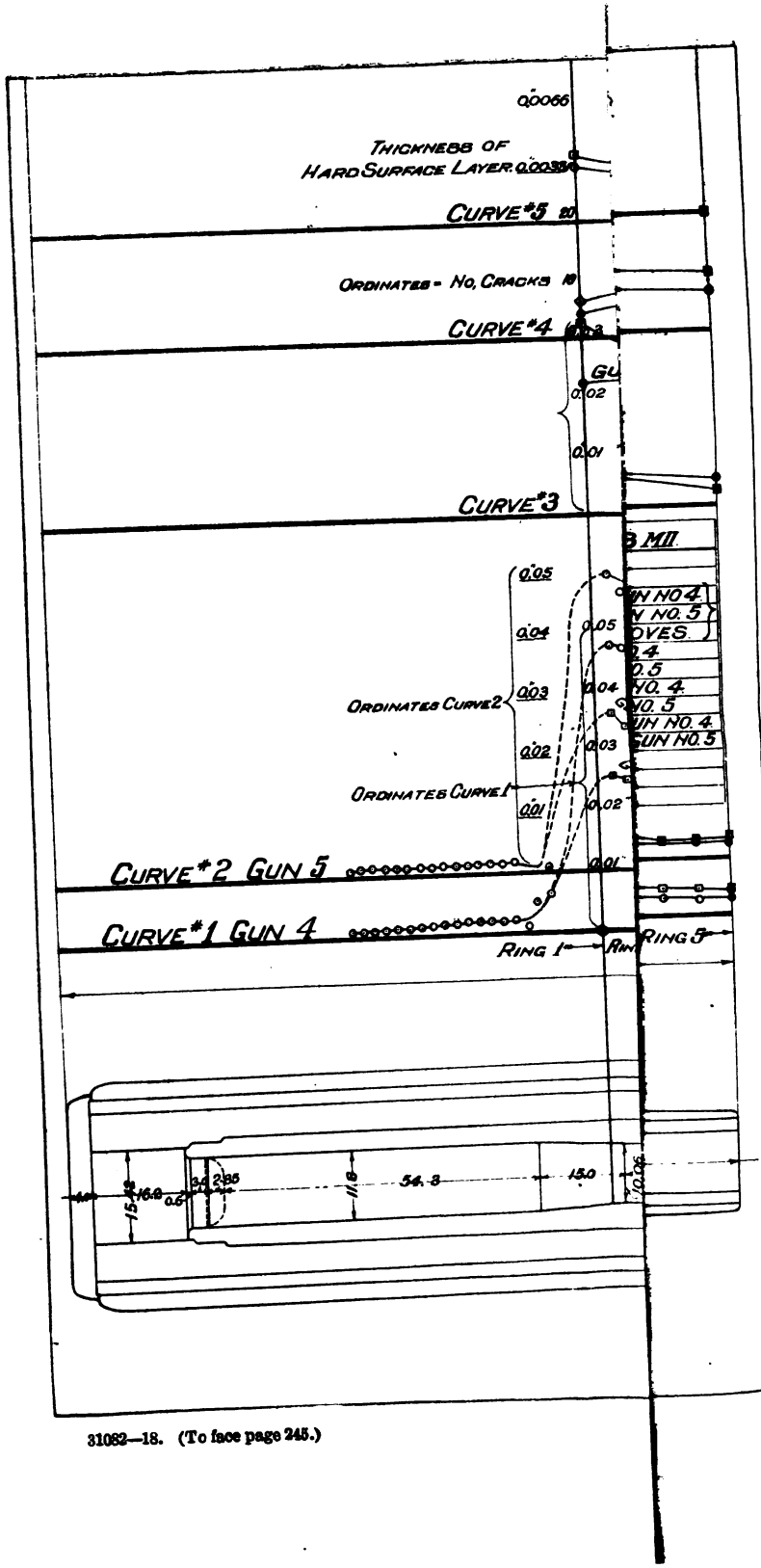
Marks.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness (number).	Charpy test.	Heat treatment.
7221 F.....	101,000	127,500	19.0	54.6	262	195	Annealed 10 hours at 850° C.; quenched in oil at 900° C.; drawn 4 hours at 500° C.
7221 F2....	100,000	127,000	19.0	49.1	262	205	Annealed 10 hours at 850° C.; quenched in oil at 900° C.; drawn 4 hours at 515° C.
7221 F3....	100,000	127,000	18.0	46.2	262	157	Annealed 10 hours at 850° C.; quenched in oil at 900° C.; drawn 4 hours at 535° C.
7221 F4....	100,000	124,500	18.0	51.9	255	155	Annealed 10 hours at 850° C.; quenched in oil at 900° C.; drawn 3 hours at 560° C.
7221 F5....	92,000	115,500	21.0	57.2	255	255	Annealed 10 hours at 850° C.; quenched in water at 800° C.; drawn 4 hours at 580° C.

CONCLUSIONS.

The results obtained do not indicate any improvement over the steel usually employed for this purpose. They are of such a nature as to warrant an additional trial at some future date on a chrome vanadium heat with a lower carbon content.

MICROGRAPH NO. 3679. 500 X.

Showing structure of white layer. Etched 2½ minutes. Showing martensite associated with troostite. 500 X.


0.0066
THICKNESS OF HARD SURFACE LAYER 0.0035
CURVE #5
ORDINATES - NO. CRACKS
CURVE #4
0.02
0.01
CURVE #3
0.05
0.04
0.03
0.02
0.01
ORDINATES CURVE 2
ORDINATES CURVE 1
CURVE #2 GUN 5
CURVE #1 GUN 4
RING 1
RING 5
54.8
15.0
11.8

EXAMINATION OF RINGS FROM BORE OF 10-INCH GUNS, NOS. 4 AND 5, MODEL 1888MII.

OBJECT.

The object of this investigation was to make a careful examination of the eroded surface of the rings and determine more definitely the nature of the hard surface layer accompanying erosion.

CONCLUSIONS.

A martensitic structure has been found in the hard surface layer. The photomicrograph No. 3679 shows martensite associated with troostite. This micrograph was taken from a specimen of gun No. 5. It was possible to develop a similar structure in all the specimens exhibiting this hard surface layer.

The other data obtained is plotted on insert following. No definite conclusions can be drawn, but as the erosion curve indicates the greatest enlargement of bore in the centering and forcing cones, it is suggested that in the next gun to be relined, rings for examination be taken from the chamber, centering, and forcing cones. It is thought that more rings taken from these locations will assist in determining the influence of the hard surface layer on the extent of erosion. The location at which the rings are to be taken should be marked on the drawing of the particular gun which is to be relined.

Due to the very uneven erosion at different points on the circumference of the rings taken from both guns No. 4 and No. 5, it is further suggested that all trepanned rings taken hereafter be marked "top" and "bottom," so that their position in the gun after removal and shipment to this arsenal will be known.

OUTLINE OF INVESTIGATION.

The rings were all calipered to determine the extent of erosion. Rings 1 and 2 from each gun were eroded more deeply on one side than on the other, and to clearly show this, they were calipered on every land and groove. Segments were cut from each ring and the width, depth, and number of cracks determined, also the thickness of the hard surface layer.

Microscopic examination was made in studying the nature of the metal near the eroded surface.

EXPERIMENTAL.

Watervliet stated that "these rings were taken from the following parts of the bore: One beginning at the origin of the rifling, one beginning one caliber from the first, one beginning at a point one-third the travel of the projectile, one beginning at a point two-thirds the travel of the projectile, and one at the muzzle. For identification purposes thay have been marked with the serial number of the gun from which taken, in addition to being numbered consecutively from 1 to 5, inclusive, beginning at the ring taken from the origin of the rifling."

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Gun No. 4 had been fired 282 rounds and gun No. 5 had been fired 285 rounds. The actual amount of metal eroded from the bore is shown in curves 1 and 2, plotted as a function of the length of gun. The erosion of both the lands and grooves and part of the powder chamber is shown. It will be noticed that in both guns toward the muzzle the grooves were more severely eroded than the lands, whereas the opposite is true in the vicinity of the forcing cone.

The average height of land determined after the rings were removed from the gun is shown in the following table:

GUN NO. 4.

Ring No.	Height of land.
	Inch.
1	0.008
2	.016
3	.057
4	.057
5	.057

GUN NO. 5.

Ring No.	Height of land.
	Inch.
1	0.009
2	.017
3	.057
4	.059
5	.060

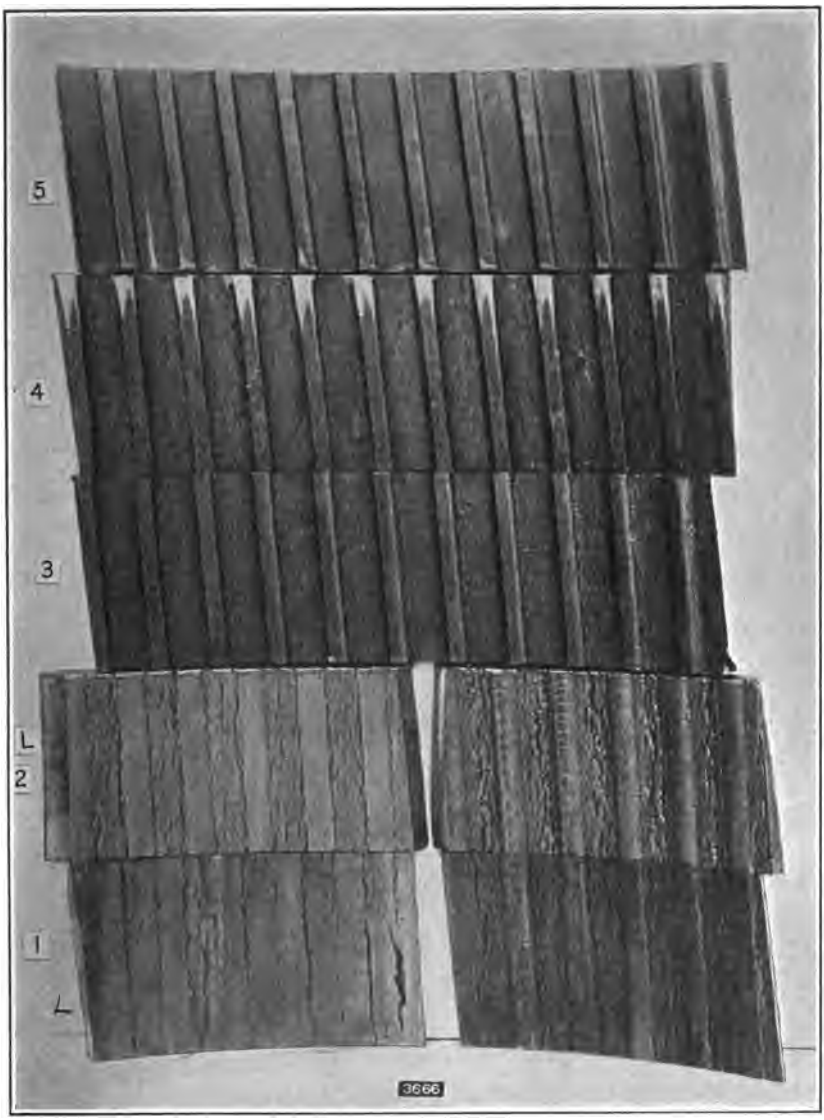
The erosion of the lands in the rings taken at the origin of rifling and one caliber forward was so irregular that the height of each land was carefully measured and the results plotted on pages 248 and 249. No means were available for determining the top and bottom of the ring. In the curves referred to above the ordinates represent the height of land and the abscissæ the consecutive lands around the tube, starting from some arbitrary point.

In examining the rings to determine the extent of cracks as well as the hard surface layer, two segments were taken from rings Nos. 1 and 2 of both guns, one where erosion was a minimum, marked H, and one where it was a maximum, marked L.

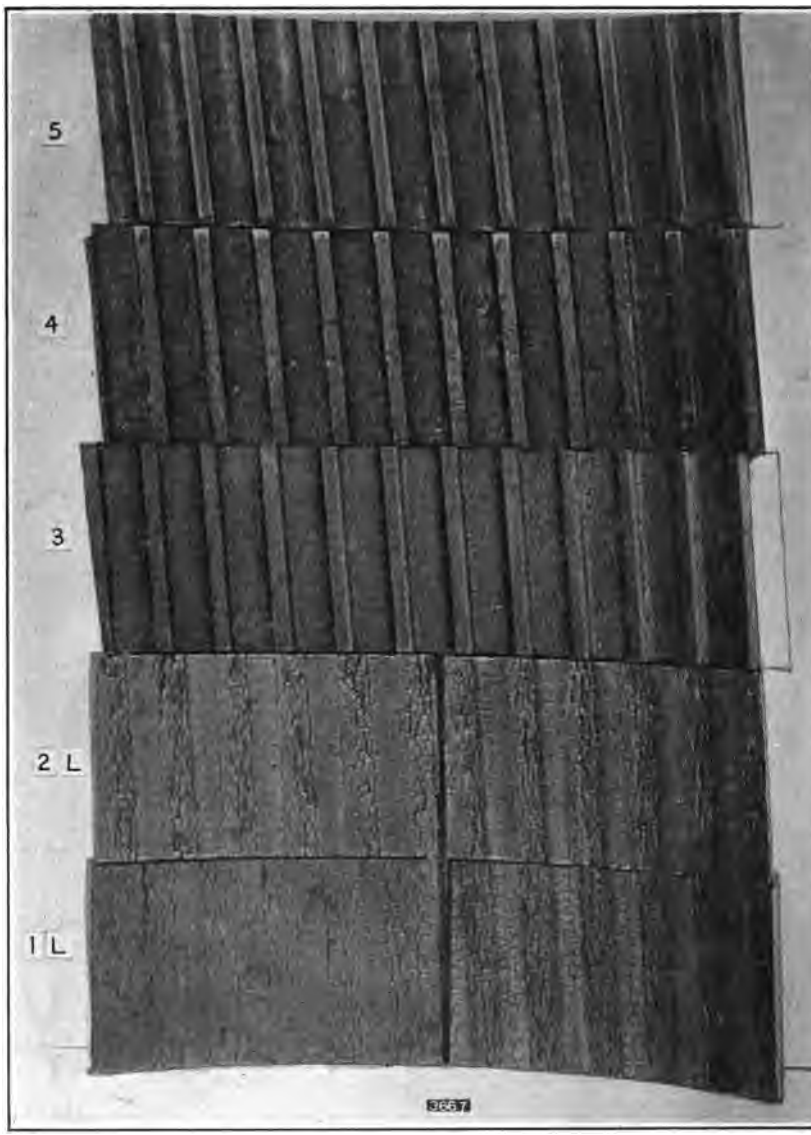
The following table gives the results of the measurements of cracks:

GUN NO. 4.

Ring No.	Depth of crack.	Width of crack.	Mean depth.	Mean width.
	Inch.	*Inch.*	*Inch.*	*Inch.*
1 L	0.022–0.052	0.005–0.018	0.036	0.010
1 H	.008– .070	.004– .016	.030	.007
2 L	.008– .048	.002– .028	.030	.012
2 H	.006– .046	.002– .018	.025	.008
3	.003– .036	.001– .014	.017	.005
4	.002– .036	.001– .014	.012	.004
5	.001– .008	.001– .003	.002	.001



247-1



247-2

GUN. NO. 5.

Ring No.	Depth of crack.	Width of crack.	Mean depth	Mean width
	Inch.	*Inch.*	*Inch.*	*Inch.*
1 L	0.006–0.039	0.001–0.011	0.024	0.004
1 H	.010– .036	.002– .010	.021	.004
2 L	.011– .040	.001– .014	.024	.005
2 H	.008– .034	.002– .030	.022	.008
3	.003– .033	.001– .012	.015	.005
4	.004– .022	.001– .012	.011	.003
5	.002– .010	.001– .006	.004	.002

These results are plotted on curve 3 of insert.

The approximate number of cracks per unit of land and groove is shown in the table below.

Ring No.	Gun No. 4.	Gun No. 5.
1 L	3	6
1 H	6	7
2 L	5	7
2 H	8	10
3	7	12
4	9	12
5	6	9

The above data are plotted as a function of the length of gun in curve 4 of insert.

Measurements of the hard surface skin were made to determine its approximate thickness.

Ring No.	Gun No. 4.	Gun No. 5.
	Inch.	*Inch.*
1 L	0.0030	0.0032
1 H	.0028	.0036
2 L	.0026	.0028
2 H	.0030	.0020
3	.0000	[1] .0016
4	.0000	.0000
5	.0000	.0000

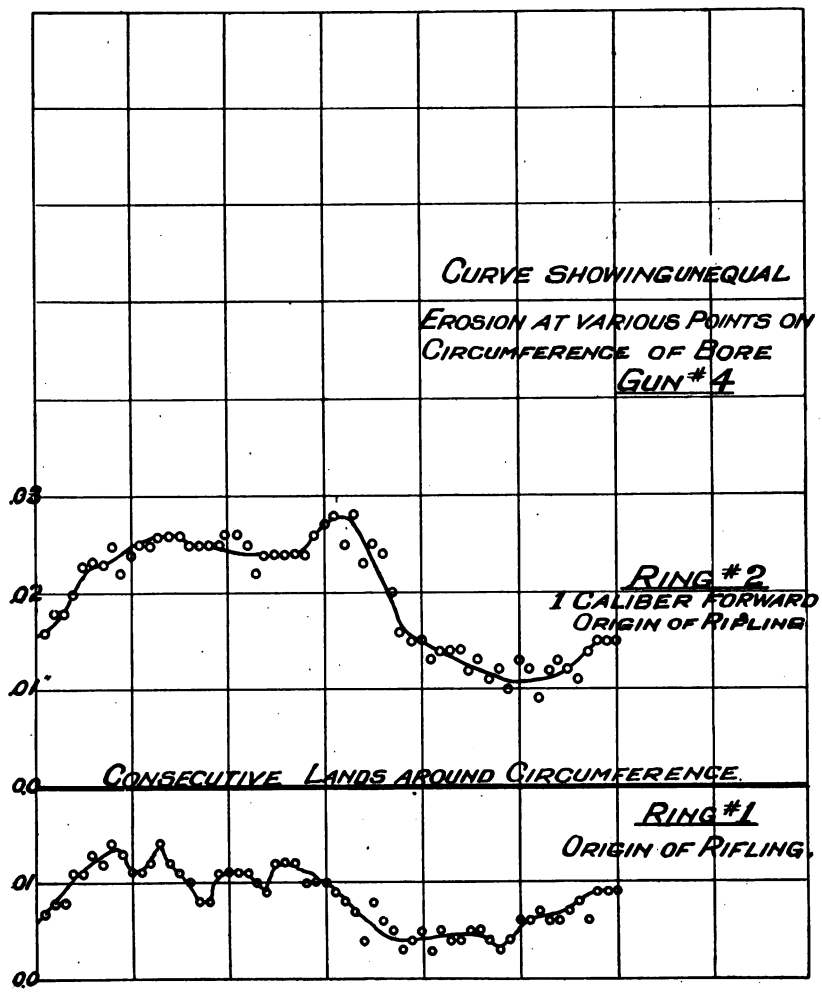
[1] Occurred in isolated spots.

The results are plotted in curve 5 of insert.

Photographs No. 3666, and No. 3667, facing this page, show segments of guns No. 4 and No 5, respectively. Two segments are shown of rings 1 and 2 for both guns, one marked L, which is much more severely eroded than the one marked H. The curves on pages 248 and 249 show this condition graphically.

Micrographs No. 3668 to No. 3678, inclusive, all at 50 diameters, show the extent of the hard surface layer. Micrograph No. 3679 was taken on the white layer after polishing the face of the bore. Polishing in this manner gave a greater area of the surface layer for examination than had previously been used. The micrograph in question shows distinct martensitic structure.

All the rings of both guns possessing the white layer, as well as those of guns formerly examined at this arsenal, were polished in this manner, and careful examination showed distinct martensite associated with troostite in every case. A longer time of etching is required to bring out this structure than is ordinarily employed. The specimen shown in micrograph No. 3679 was etched two and one-half minutes in a solution of 4 per cent nitric acid in alcohol.


CURVE SHOWING UNEQUAL
EROSION AT VARIOUS POINTS ON
CIRCUMFERENCE OF BORE
GUN #4
.03
.02
.01
RING #2
1 CALIBER FORWARD
ORIGIN OF RIFLING
CONSECUTIVE LANDS AROUND CIRCUMFERENCE.
.00
.01
.00
RING #1
ORIGIN OF RIFLING.

GUN NO. 4. RING NO. 1.

Side showing maximum erosion and white layer. 50 X.

248-1

GUN NO. 4. RING NO. 1.

Side showing minimum erosion. 50 X.

GUN NO. 4. RING NO. 2.

Side showing maximum erosion. 50 X.

GUN NO. 4. RING NO. 2.

Side showing minimum erosion. Micrograph taken at base of driving side of land showing the uneven surface at this point. 50 X.

GUN NO. 4. RING NO. 3.

Numerous cracks but no white layer present. 50 X.

GUN NO. 5. RING NO. 1.

Side showing maximum erosion, large crack and white layer. 50 X.

249-1

GUN NO. 5. RING NO. 1.

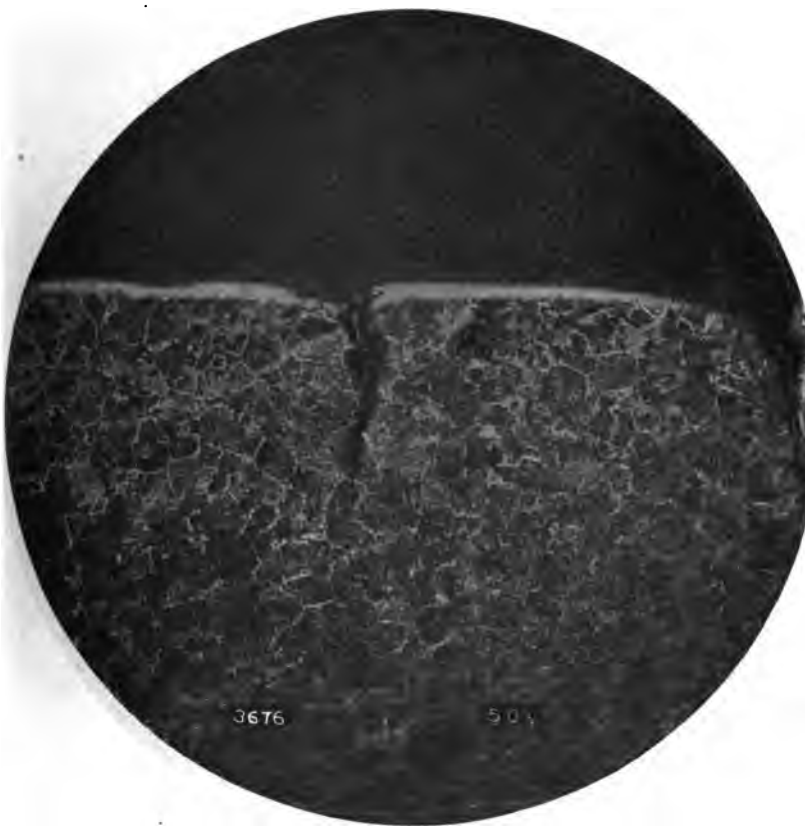
Side showing least erosion. White layer and crack visible. 50 X.

249-2

GUN NO. 5. RING NO. 2.

Side showing maximum erosion. White layer very distinct. 50 X.

249-3



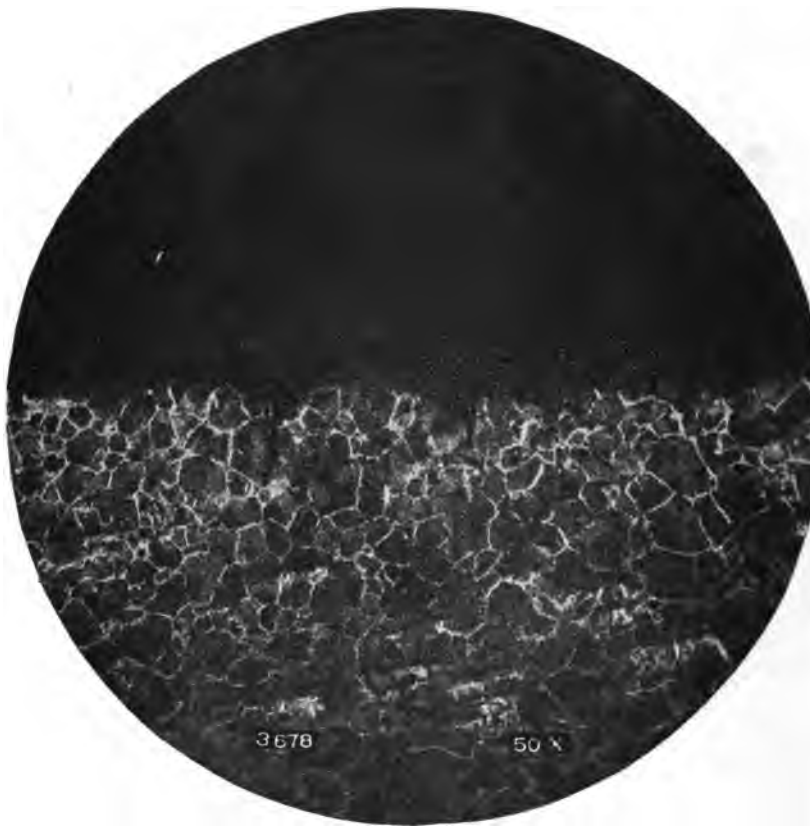
GUN NO. 5. RING NO. 3.

Photograph taken in groove. White layer present in places in groove only. 50 X.

GUN NO. 5. RING NO. 2.

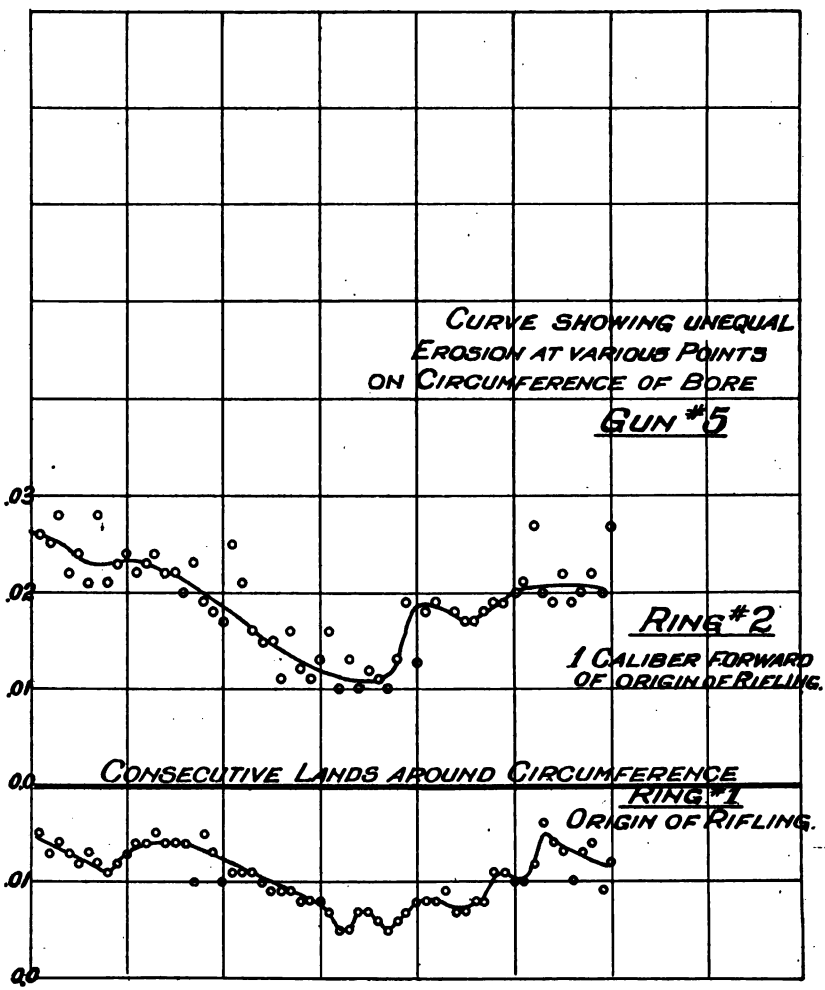
Side showing minimum erosion. Thin white layer and large crack visible. 50 X.

249-5



GUN NO. 5. RING NO. 3.

Showing no white layer present. Taken in grooves to compare with Micrograph No. 3677. 50 X.


CURVE SHOWING UNEQUAL
EROSION AT VARIOUS POINTS
ON CIRCUMFERENCE OF BORE
GUN #5
.03
.02
.01
0.0
RING #2
1 CALIBER FORWARD
OF ORIGIN OF RIFLING.
CONSECUTIVE LANDS AROUND CIRCUMFERENCE
RING #1
ORIGIN OF RIFLING.
.01
0.0

INSULATING MATERIAL.

OBJECT.

The object of this investigation was to determine the relative merits of molded insulating compounds used in carriage construction. This test was confined to the mechanical properties of these materials. Four samples were submitted for test, marked as follows: A, B, C, and D.

CONCLUSIONS.

The following tables abstract the data obtained and show the relative rank in each test of the material examined:

RELATIVE RANKING OF MATERIALS IN ABSORPTION TESTS.

Rank.	Absorption with raw edges.		Absorption with minimum of raw edge exposed.	
	Cold.	Hot.	Cold.	Hot.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	C 1.2	C 4.8	A 0.37	C 3.0
2	B 1.8	B 7.5	C 0.8	A 4.4
3	A 3.3	A 7.7	B 1.5	B 4.7
4	D 7.3	D 7.9	D 6.9	D 8.8

Remarks.—With a great deal of raw surface exposed, the ranking is C, B, A, and D. With a minimum of raw edge exposed, material A stands up well. Material D is at the bottom of the list throughout.

BRINELL HARDNESS.

Rank.	As received.	After soaking, cold water.	After soaking, hot water.
1	B 49	C 35	C 27.8
2	A 41.4	B 25.1	B 24.2
3	C 40.6	A 21	A 16.5
4	D 14.8	D 10.6	D 10.7

Remarks.—Material B, A, and C all have a Brinell hardness over 40 as received. Material C retains its hardness after soaking better than the other samples. The ranking after either cold or hot water soaking is C, B, A, and D.

TRANSVERSE TESTS.

Rank.	As received.	After soaking in cold water.	After soaking in hot water.
1	B 9,857	B 9,758	B 4,880
2	C 6,795	C 8,147	C 3,825
3	A 3,180	A 2,802	D 2,395
4	D 3,120	D 2,595	A 1,886

Remarks.—The transverse tests show the following order of merit on the material as received: B, C, A, and D. After soaking in hot water, materials A and D are inverted in their order.

EXPERIMENTAL.

The outline followed in obtaining the data on which the above conclusions were based was as follows:

(1) Transverse tests as received.
(2) Hardness tests as received.
(3) Transverse tests after soaking in cold water.
(4) Hardness tests after soaking in cold water.
(5) Transverse tests after soaking in hot water.
(6) Hardness tests after soaking in hot water.
(7) Determination of water absorbed after soaking in hot water and in cold water.

The absorption tests were conducted as follows: Specimens approximately 2½ by 0.5 by 0.5 inch were sawed from the blocks for test. These samples are described in the data tables as having raw edges exposed. The samples of A and B material with no raw edge were disks 2½ inches in diameter. Both C and D material had two raw edges where the 2½ inch square block was taken from the piece.

The samples were washed in dilute solution of potassium hydrate and then immersed in beakers of tap water, the temperature of the water being recorded from time to time. The following table gives the detailed results of the test. This test extended over a period of 210 hours.

ABSORPTION TESTS.

[Time, 210 hours. Average temperature, cold water, 23.2° C.; hot water, 55.2° C.]

COLD.

Marks.	Dimensions.			Weight.		Absorption.		
	Length (inches).	Width (inches).	Thickness (inches).	Dry (grams).	Wet (grams).	Increase in weight (grams).	Per cent increase.	Mean.
A 3	2.668	0.495	0.500	20.29	20.75	0.46	2.2	3.3
A 4	2.781	.493	.507	20.53	21.28	.75	3.6	
A 7	2.668	.501	.508	21.00	21.78	.78	3.7	
A 15	2.695	.500	.510	21.18	22.00	.82	3.8	
A	[1] 2.761	.....	.498	94.10	94.45	.35	.37	.....

[1] Equals diameter.

Absorption tests—Continued.

HOT.

Marks.	Dimensions.			Weight.		Absorption.		
	Length (inches).	Width (inches).	Thickness (inches).	Dry (grams).	Wet (grams).	Increase in weight (grams).	Per cent increase.	Mean.
A 2	2.676	0.496	0.491	20.02	22.48	2.46	12.2	7.7
A 8	2.723	.500	.503	20.98	21.78	.80	3.8	
A 11	2.537	.501	.525	20.38	22.02	1.64	8.0	
A 12	2.620	.500	.516	20.83	22.28	1.45	6.9	
AA	[1] 2.764	.....	.506	94.10	98.27	4.17	4.4	.....

COLD.

B 6	2.681	0.502	0.475	13.81	14.03	0.22	1.5	1.7
B 11	2.582	.501	.494	13.81	14.07	.26	1.8	
B 13	2.670	.502	.478	13.78	14.02	.24	1.7	
B 14	2.683	.502	.502	14.65	14.95	.30	2.0	
BB	[1] 2.753	.....	.502	65.31	66.32	1.01	1.5	.....

HOT.

B 1	2.645	0.501	0.477	13.66	14.66	1.00	7.3	7.5
B 4	2.701	.500	.488	14.31	15.41	1.10	7.6	
B 18	2.682	.501	.492	14.32	15.38	1.06	7.4	
B 20	2.754	.498	.504	14.97	16.13	1.16	7.7	
B	[1] 2.741	.....	.507	65.35	68.46	3.11	4.7	.....

COLD.

C 1	2.627	0.501	0.510	14.16	14.33	0.17	1.2	1.17
C 4	2.615	.498	.514	14.12	14.30	.18	1.2	
C 9	2.589	.500	.515	14.05	14.21	.16	1.1	
C 16	2.662	.500	.503	14.06	14.24	.18	1.2	
C 20	2.491	2.494	.494	64.38	64.87	.49	.76	.....

HOT.

C 3	2.625	0.500	0.513	14.12	14.78	0.66	4.6	4.8
C 5	2.606	.496	.515	14.03	14.70	.67	4.7	
C 10	2.590	.500	.515	13.97	14.68	.71	5.0	
C 13	2.665	.498	.502	13.99	14.70	.71	5.0	
C 21	2.488	2.493	.494	64.25	66.22	1.97	3.0	.....

COLD.

D 2	2.728	0.502	0.554	25.75	27.45	1.70	6.6	7.2
D 5	2.697	.505	.545	24.68	26.55	1.87	7.5	
D 14	2.691	.498	.540	24.05	25.87	1.82	7.5	
D 15	2.675	.499	.537	23.74	25.50	1.76	7.4	
D 20	2.452	2.463	.532	101.60	108.69	7.09	6.9	.....

HOT.

D 3	2.727	0.500	0.553	25.46	27.42	1.96	7.6	7.6
D 7	2.667	.500	.543	23.80	25.71	1.91	8.0	
D 12	2.692	.495	.543	24.33	26.25	1.92	7.8	
D 13	2.693	.500	.542	24.26	26.24	1.98	8.1	
D 21	2.462	2.448	.526	100.12	108.97	8.85	8.8	.....

[1] Equals diameter.

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Material.	Nature of specimen.	Absorption, mean value.	Average temperature.
		Per cent.	
A	Transverse test specimen with raw edges	3.3	Cold water, 23.2.
A	do	7.7	Hot water, 55.2.
A	Round disk, no raw edges	.37	Cold water.
A	do	4.4	Hot water.
B	Transverse test specimen with raw edges	1.8	Cold water.
B	do	7.5	Hot water.
B	Round disk, no raw edges	1.5	Cold water.
B	do	4.7	Hot water.
C	Transverse test specimen with raw edges	1.2	Cold water.
C	do	4.8	Hot water.
C	Square plate, two edges raw	.8	Cold water.
C	do	3.0	Hot water.
D	Transverse test specimen with raw edges	7.3	Cold water.
D	do	7.9	Hot water.
D	Square plate with two raw edges	6.9	Cold water.
D	do	8.8	Hot water.

HARDNESS TESTS.

Hardness tests were obtained on samples of each material as received, and after soaking in cold water and in hot water, respectively. A pressure of 500 kilograms was used with a 10-millimeter ball.

Sample.	Hardness as received.	Hardness after soaking in cold water.	Hardness after soaking in hot water.
A	38	(1)	(1)
	40	(1)	(1)
	43	(1)	(1)
	43	.....	15.3
	43	21	17.8
Mean	41.4	21	16.5
B	48	25.9	23.8
	50	27.2	24.9
	50	25.9	23.8
	48	23.8	23.8
	48	22.8	24.9
Mean	49	25.1	24.2
C	40	35	29.7
	40	36	28.4
	43	34.5	26.5
	40	34.5	27.2
	40	37	27.2
Mean	40.6	35.4	27.8
D	16.6	11.1	9.9
	14.5	10.3	12.4
	11.1	10.3	9.9
	15.3	.....	.....
	17.8	.....	.....
	13.3	.....	.....
Mean	14.8	10.6	10.7

[1] Specimen scaled off under ball.

The following photograph is introduced at this point to show the behavior of the samples under the ball test. The samples are arranged on the photograph in the following order: A, B, C, and D, from the top downward. From left to right the order is, as received, after soaking in cold water, and after soaking in hot water. Sample A, after soaking, was subject to spalling under the Brinell ball. Sample D cracked as shown in the photograph.

TRANSVERSE TESTS.

Twelve specimens from each sample were tested for transverse strength, four as received, four after soaking in cold water, and four after soaking in hot water. The small Emery hydraulic machine was used and the distance between supports was 2 inches. The following table gives the detailed results. The formula used in calculating the modulus of rupture was $R = \frac{3\,P\,l}{2\,b\,d^2}$.

NO TREATMENT—AS RECEIVED.

Marks.	Width (inches).	Depth (inches).	Tensile strength (pounds).	Modulus of rupture.	
				Pounds (per square inch).	Mean pounds (per square inch).
A 5	0.501	0.498	115	2,780	3,180
A 6	.501	.498	108	2,610	
A 10	.501	.499	148	3,950	
A 13	.501	.495	141	3,380	
B 3	.501	.485	400	10,000	9,857
B 9	.500	.505	450	10,380	
B 12	.502	.475	430	11,210	
B 15	.501	.505	340	7,840	
C 2	.500	.512	333	7,680	6,795
C 7	.501	.501	306	7,340	
C 15	.500	.504	253	6,070	
C 17	.498	.504	254	6,090	
D 1	.499	.555	209	3,990	3,120
D 4	.498	.552	90	1,780	
D 6	.498	.542	162	3,320	
D 8	.499	.535	165	3,390	

SOAKED IN COLD WATER—WATER 23.2° C.

A 3	0.498	0.500	138	3,310	2,802
A 4	.495	.515	131	2,910	
A 7	.505	.519	114	2,480	
A 15	.502	.518	113	2,510	
B 6	.503	.481	347	9,050	9,758
B 11	.502	.501	433	10,390	
B 13	.503	.495	405	9,720	
B 14	.503	.510	428	9,870	
C 1	.504	.512	391	9,020	8,147
C 4	.500	.517	353	7,840	
C 9	.502	.518	346	7,680	
C 16	.502	.506	349	8,050	
D 2	.507	.555	169	3,200	2,595
D 5	.509	.549	58	1,130	
D 14	.503	.543	159	3,270	
D 15	.505	.540	137	2,780	

SOAKED IN HOT WATER.

A 2	0.512	0,552	123	2,410	1,886
A 8	.504	.546	106	2,100	
A 11	.516	.575	62	1,150	
A 12	.514	.563			
B 1	.512	.507	207	4,680	4,880
B 4	.511	.519	226	4,930	
B 18	.512	.520	256	5,580	
B 20	.509	.535	216	4,370	
C 3	.505	.530	171	3,600	3,825
C 5	.503	.533	172	3,680	
C 10	.507	.533	210	4,420	
C 13	.506	.522	165	3,600	
D 3	.503	.556	130	2,460	2,395
D 7	.503	.547	120	2,350	
D 12	.499	.548	131	2,590	
D 13	.502	.547	110	2,180	

INVESTIGATION OF RINGS FROM 4.7-INCH HOWITZER.

MATERIAL.

Seven rings were received from Watervliet Arsenal, marked as follows:

4.7-inch howitzer, model 1912, No. 53, 136728B2 F2.
4.7-inch howitzer, model 1912, No. 52, 136728B2 F1.
4.7-inch howitzer, model 1912, No. 51, 136712B1 F4.
4.7-inch howitzer, model 1912, No. 50, 136712B2 F1.
4.7-inch howitzer, model 1912, 17852, 136712B2 F2.
4.7-inch howitzer, model 1912, No. 49, 136712B3 F3.
4.7-inch howitzer, model 1912, No. 47, 136712B3 F1.

The dimensions of ring No. 50 were such that no test specimens could be taken, consequently the investigation was confined to the other six rings.

OBJECT.

The object of this investigation was to determine the physical properties of the metal in each tube and the relation of these properties to the presence of streaks. This investigation was undertaken subsequent to the failure at this Arsenal to produce satisfactory bodies for the 4.7-inch howitzers. The above rings were forwarded to this Arsenal from Watervliet Arsenal, and represent forgings secured from the Bethlehem Steel Co.

CONCLUSIONS.

It is impossible to draw any definite conclusions from this investigation. Certain general deductions can be made, however, which are of interest.

The iodine etching of forgings for the location of test specimens is not only practicable but very essential. If proper precautions were taken to locate test specimens for acceptance by this means, the necessity of an additional clause in the specifications to allow rejection on account of streaks would be less urgent.

If a test specimen is located in a region containing the maximum number of streaks and still shows good elongation and contraction, the shock test will in all probability be good and the forging suitable for gun construction. That this condition will exist is very doubtful, and badly streaked metal will generally fail in elongation and contraction of area.

Being low in ductility, the shock test will be poor and the material consequently unsafe for ordnance purposes. Until it is possible to introduce a uniform and reliable shock test, the ductility as recorded by the elongation and contraction of area in the tensile test must be maintained at the highest possible figure consistent with the elastic limit and tensile requirements.

Some of the rings from the 4.7-inch howitzer, model of 1912, reported herein, did not meet the specifications regarding elongation and reduction of area, especially when the tests were located in the streaked portions of the ring. The shock test as determined by the Charpy impact machine was likewise low.

EXPERIMENTAL.

The procedure followed for each tube was:—

(1) Iodine etching to determine the presence or absence of streaks.

(2) Location of tensile and Charpy specimens from the data obtained by iodine etching. The attempt was made to locate one tensile specimen in the badly streaked portion of each tube and another specimen in a portion free from streaks wherever this was feasible.

(3) Microexamination of the metal in each tube.

To facilitate the presentation of the data obtained, the results of the tests on each ring, together with the photograph after iodine etching and the micrographs, are recorded on one page.

Although the conclusions drawn from the results presented must be very general, the following are at least of interest.

Dividing the rings into two classes containing three rings each, (*a*) badly streaked, (*b*) not as badly streaked as (*a*), the following arrangement seems justified.

(*a*) Rings 53, 52, 17852.

(*b*) Rings 51, 49, 47.

Means on class (a) rings.

Yield point	pounds per square inch..	61,100
Tensile strength	do....	93,500
Elongation	per cent..	20.1
Contraction of area	do....	29.4
Charpy impact test	foot-pounds per square inch..	179
Brinell hardness number		183

Means on class (b) rings.

Yield point	pounds per square inch..	61,900
Tensile strength	do....	93,000
Elongation	per cent..	22.2
Contraction of area	do....	41.0
Charpy impact test	foot-pounds per square inch..	186.5
Brinell hardness number		184

From an examination of the mean values the following facts are evident.

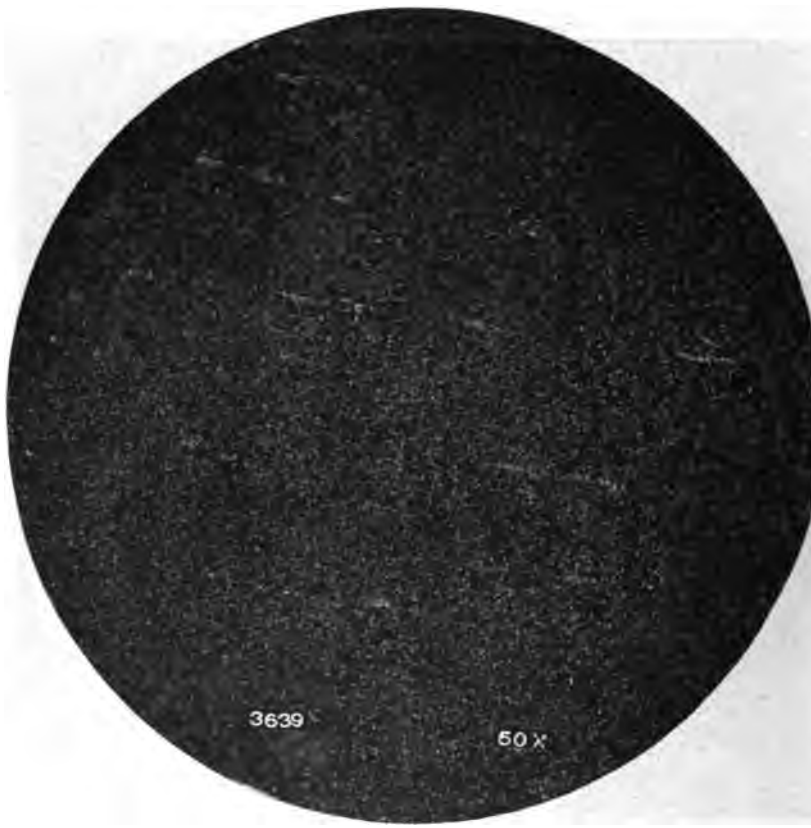
(1) The presence of streaks has apparently little effect on the location of the "yield point" or value of the tensile strength.

(2) Class (*a*)—badly streaked rings—show a less elongation and contraction of area than class (*b*)—rings not so badly streaked as class (*a*).

(3) The shock test on class (*a*) gave a lower value than on class (*b*).

It is also of interest to note that ring 53, showing an elongation of 18 per cent and contraction of 20.5 per cent, gave a Charpy test of only 157 foot-pounds per square inch, thus bearing out the conclusions expressed on the first page of this report.

257–1



MICROGRAPH NO. 3639. 50 X.

Note presence of slag inclusions throughout metal. These small elongated slag inclusions were common to the metal of this ring. It is thought that this condition is often more serious than large low carbon streaks visible to the unaided eye.

MICROGRAPH NO. 3640. 500 X. SORBITIC STRUCTURE.

Ring 53.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
53a.....	58,500	94,500	18.0	20.5	[1] 157	183	Many streaks.
53b.....	62,000	99,000	18.0	20.5		187	Do.

[1] Average of four tests.

Both specimens very badly streaked. Contraction of area very poor. Charpy strength also rather low.

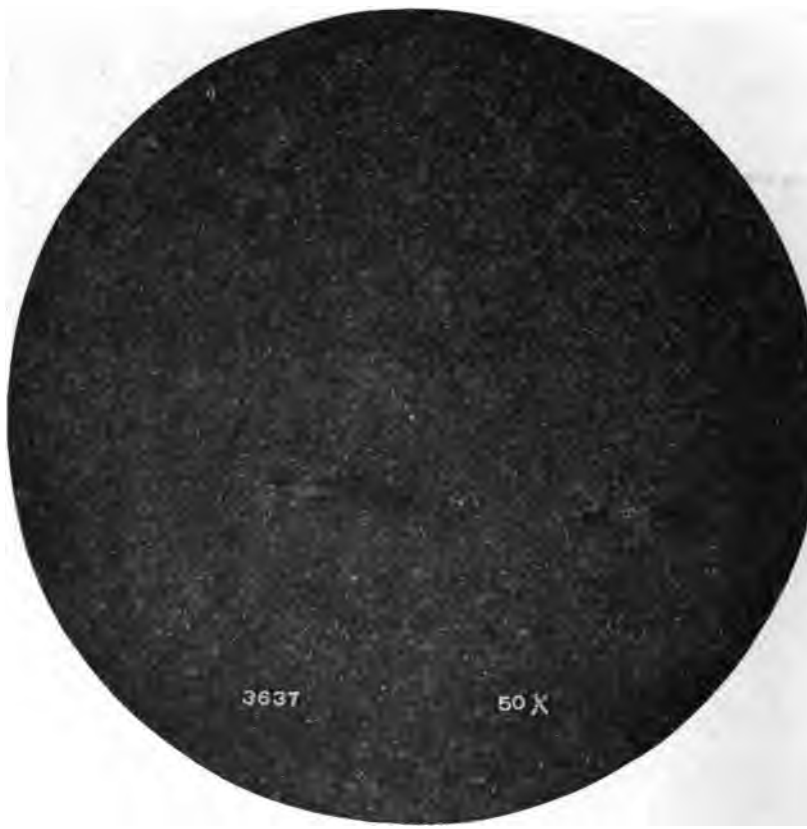
Ring 52.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
52a.....	60,500	90,000	25.5	43.3	[1] 193	179	Very few spots.
52b.....	62,000	93,000	21.0	34.0		183	Many more spots than A.

[1] Average of four tests.

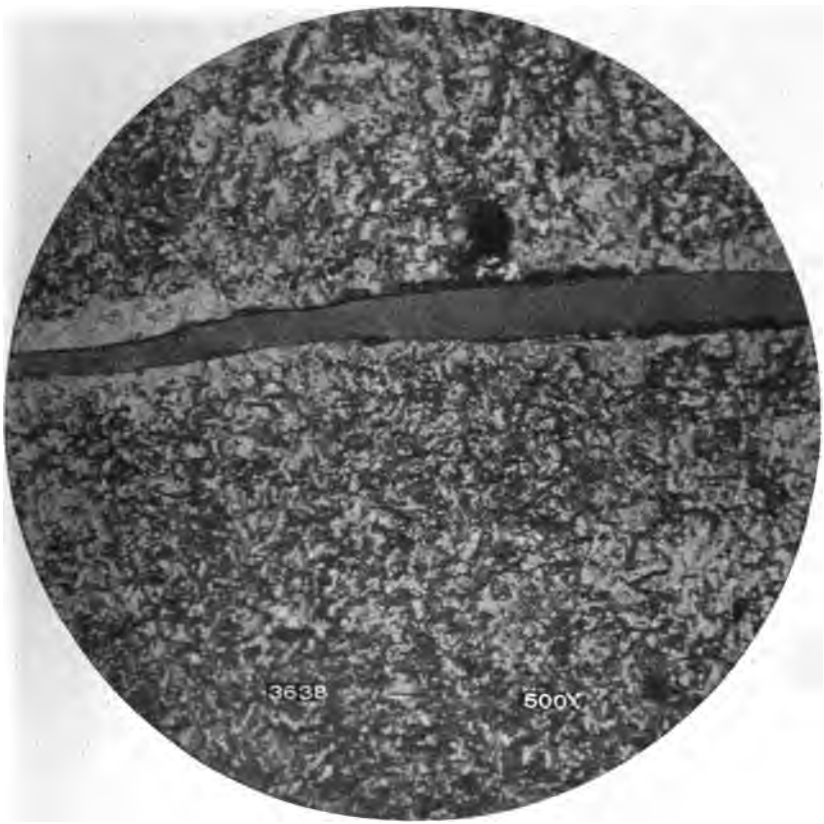
It is to be noted in the above tests that 52b, containing more streaks than 52a, also shows less contraction of area.

258–1



MICROGRAPH NO. 3637. 50 X.

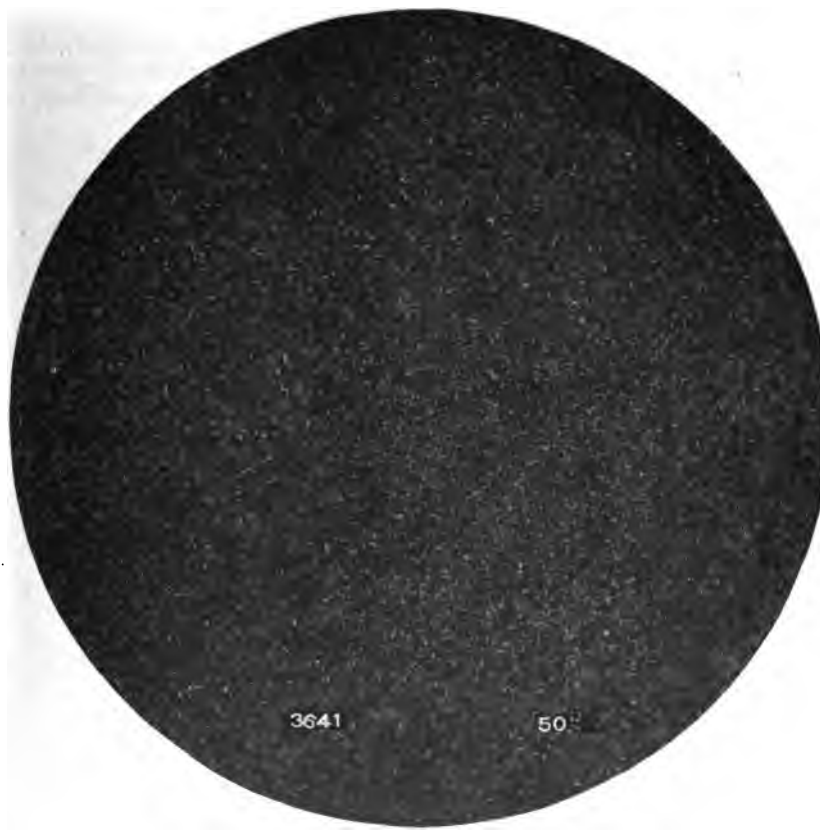
Structure finer than any ring examined in this experiment. Note slag inclusions.



MICROGRAPH NO. 3638. 500 X.

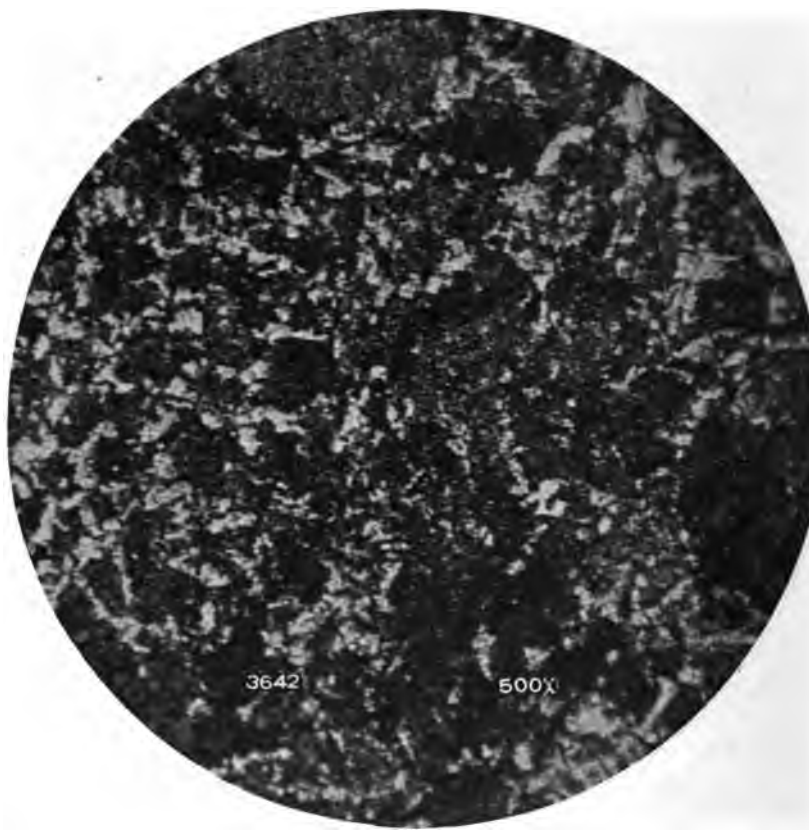
Located on streak. Note slag inclusion and also low carbon of streak.

259–1



MICROGRAPH NO. 3641. 50 X.

Structure finer than rings 47 or 49.



MICROGRAPH NO. 3642. 500 X.

Structure sorbitic with excess ferrite.

Ring 17852.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
17852a.....	63,000	93,500	17.5	24.0	[1] 187	187	Great many streaks.
17852b.....	61,000	91,000	20.5	34.0		179	Do.

[1] Average of four tests.

This ring had many more streaks than either 47 or 49, as did also test specimens taken from same. Note low figure for elongation and contraction of test 17852a.

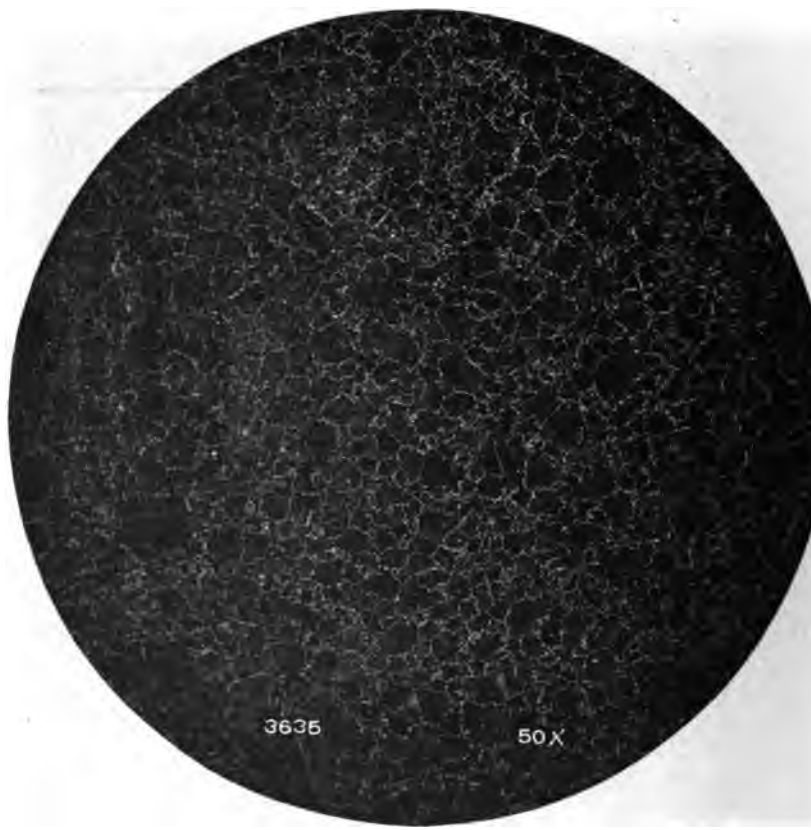
Ring 51.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
51a.....	59,500	94,000	16.0	27.4	[1] 181.5	187	Free from streaks.
51b.....	60,500	94,000	24.5	46.2		187	Do.

[1] Average of four tests.

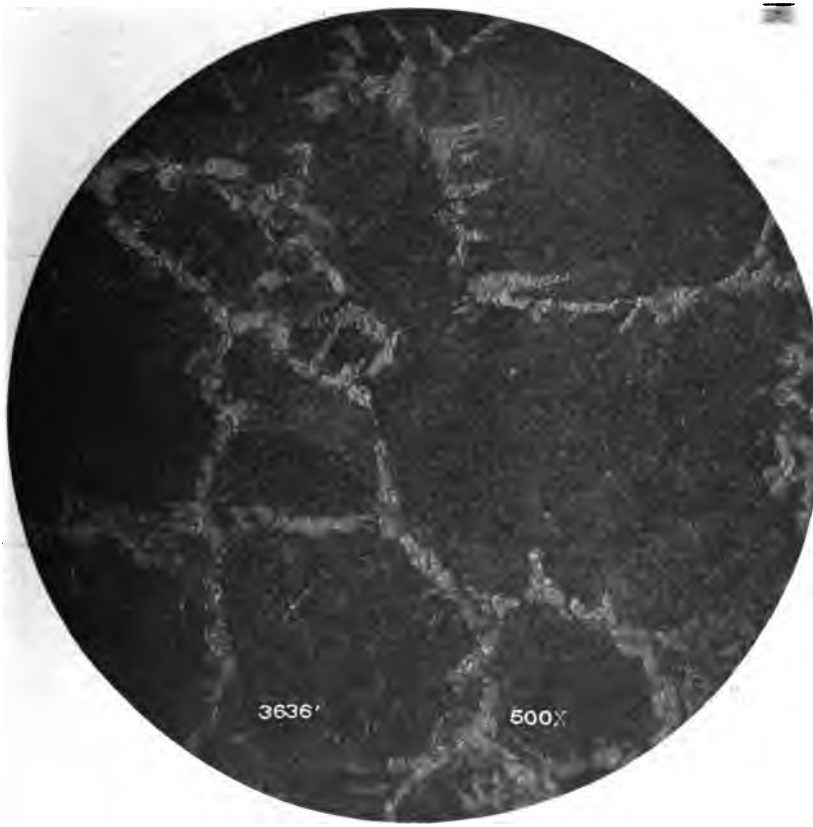
Specimen 51a broke near shoulder. It is thought that location of break makes this test not representative. This ring, although relatively free from large streaks, is full of many very fine ones.

260–1



MICROGRAPH NO. 3635. 50 X.

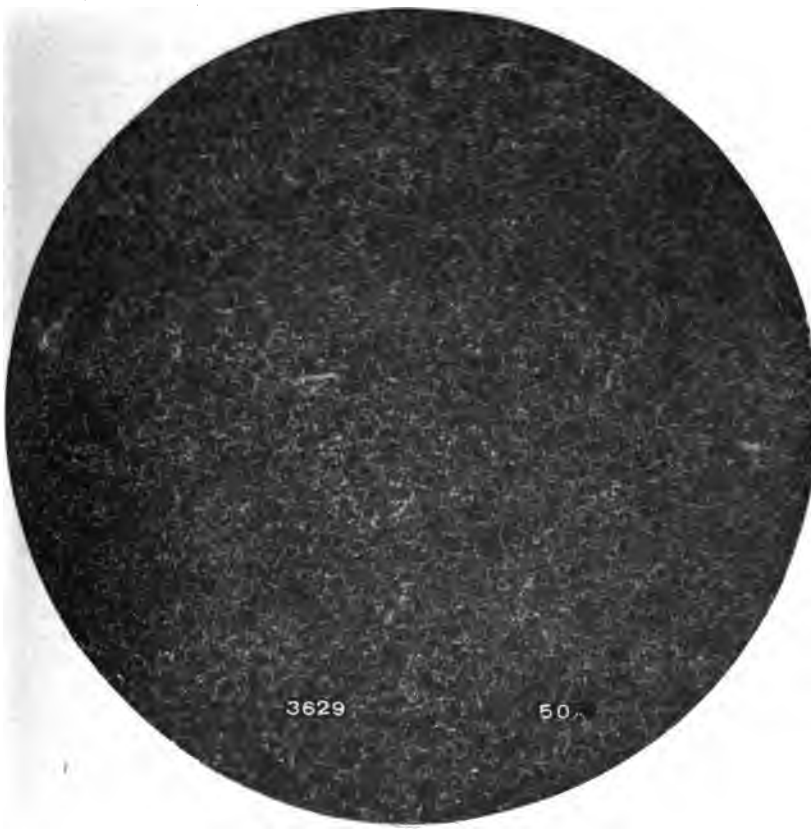
Structure much coarser than any of the other rings.



MICROGRAPH NO. 3636. 500 X.

Structure is almost granular pearlite.

261-1



MICROGRAPH NO. 3629. 50 X.

Structure very similar to Ring 47. To be compared with Micrograph No. 3627.

MICROGRAPH NO. 3630. 500 X.

Structure very similar to Ring 47. To be compared with Micrograph No. 3628.

Ring 49.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
49a.....	64,500	94,500	22 5	46 2	[1] 188	183	Not many streaks.
49b.....	62,500	94,000	23.5	46.2		183	Do.

[1] Average of four tests.

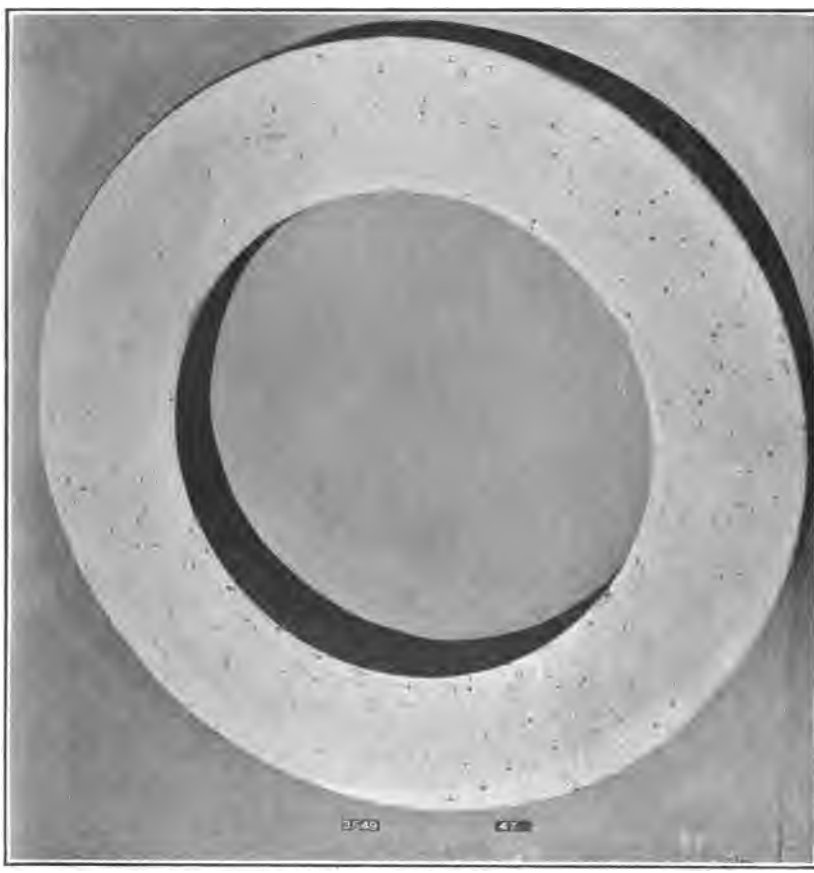
There were fewer streaks in the test specimens cut from this ring than were present in ring 47.

Ring No. 47.

Marks.	Yield point.	Tensile strength.	Elongation (per cent).	Contraction (per cent).	Charpy.	Brinell.	Remarks.
47a.....	64,000	92,500	22.5	46.2	[1]190	183	Not many streaks.
47b.....	60,500	89,000	24.5	34,0		179	More streaks than 47a.

[1] Average of four specimens.

Specimen 47b, which showed more streaks than 47a, had a less reduction of area. The elongation was greater in 47b than in 47a, but this increase of elongation was due to the fact that the metal opened up along the streaks, giving a false elongation.



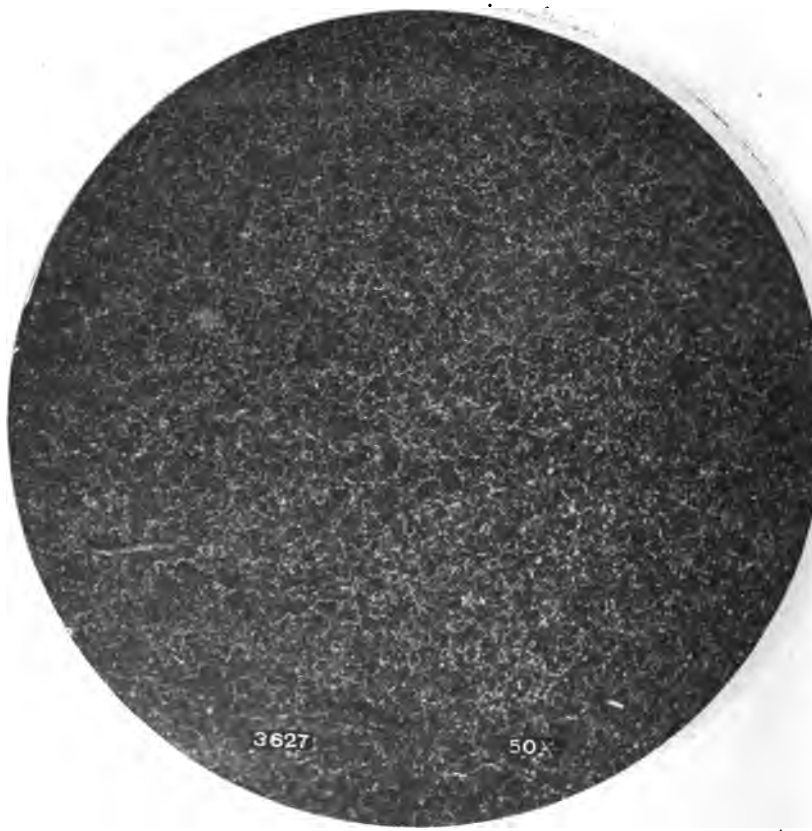
262–1

MICROGRAPH NO. 3625. 50 X.

Showing streak. Many slag inclusions present in low carbon area comprising streak.

MICROGRAPH NO. 3626. 500 X.

Located on streak. Comparison of this structure with that shown above, Micrograph No. 3628, shows the great difference between carbon content of the metal proper and a streak in same metal.



MICROGRAPH NO. 3627. 50 X.

On sound metal, free from streaks.

MICROGRAPH NO. 3628. 500 X.

On sound metal free from streaks. Sorbitic with excess ferrite.

INVESTIGATION OF STREAKED GUN TUBE.

The object of this investigation was to determine if the ghost lines which were present in B tube No. 132893B1 would be a source of weakness in this tube.

CONCLUSIONS.

The results obtained on eight tensile tests show that there was very little difference in the physical properties of any of the specimens. Some of the specimens tested included a number of ghost-lines, whereas the others were practically free from same.

The results of the Charpy tests show that the material of the tube had very good shock resistance. The Charpy results on the different specimens were erratic, but no connection could be found between this irregularity and the presence of ghost-lines in the specimens.

The results of the tensile tests show that the material of this tube does not meet the required specifications, and an additional clause in the specifications relative to streaks would not be necessary to cause the rejection of this tube.

MATERIAL.

The material used in this investigation was a ring 2¾ inches thick, which was cut from the muzzle end of B tube No. 132893B1 from 14-inch gun No. 16.

EXPERIMENTAL.

Three specimens marked "A," "B," and "C," were cut from this ring, as shown in photograph No. 3544, for microscopic examination. Eight tensile and eight Charpy tests were taken from the ring in the location shown also on photograph No. 3544. Two specimens were taken at each location, one directly under the other, the specimens being so located that some would be relatively free from streaks, whereas others would contain streaks in the maximum amount. Both the Charpy and tensile specimens were etched with iodine before testing. Photographs No. 3547 and 3548 show the appearance of the tensile specimens after iodine etching. It is to be noted at this point that the white spots on the specimens are the end of the streaks. In most cases these streaks were continuous throughout the specimen, and the streak could be located on the opposite side. Both the specimens marked "J" were very streaky. Both specimens marked "C" contained about the same number of streaks, whereas both specimens marked "F" and "H" were relatively free from streaks. The specimens appear in the photographs in the order tested.

TENSILE TESTS.

Marks.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness.
16 H	54.000	84.000	23.0	46.2	167
16 H	53.000	83.500	21.0	37.2	167
16 J	54.000	84.000	24.5	43.3	167
16 J	53.000	83.500	24.5	43.3	171
16 F	52.000	84.000	26.5	43.3	175
16 F	54.000	84.000	25.0	43.3	171
16 G		85.000	23.0	43.3	171
16 G	54,000	85,000	22.0	43.3	171

An inspection of the results of the tensile tests shows very close agreement in yield point, tensile strength, elongation and contraction. As previously pointed out, these results are much lower than those obtained at the works of the manufacturer, and are sufficient in themselves to cause rejection of the material.

Photographs No. 3546 and No. 3545 show the Charpy specimens after etching with iodine. Specimen No. 16L1 has a streak directly under the notch, as has also specimen 16N1. These are the only specimens in which the streak was continuous and under the notch. Specimens 16K2, 16M1, 16M2 show streaks on one side of bar only. Although the foot pounds absorbed per square inch varied in the specimen tested from 231 to 302, no apparent weakening or variation can be directly ascribed to the presence of streaks.

CHARPY TESTS.

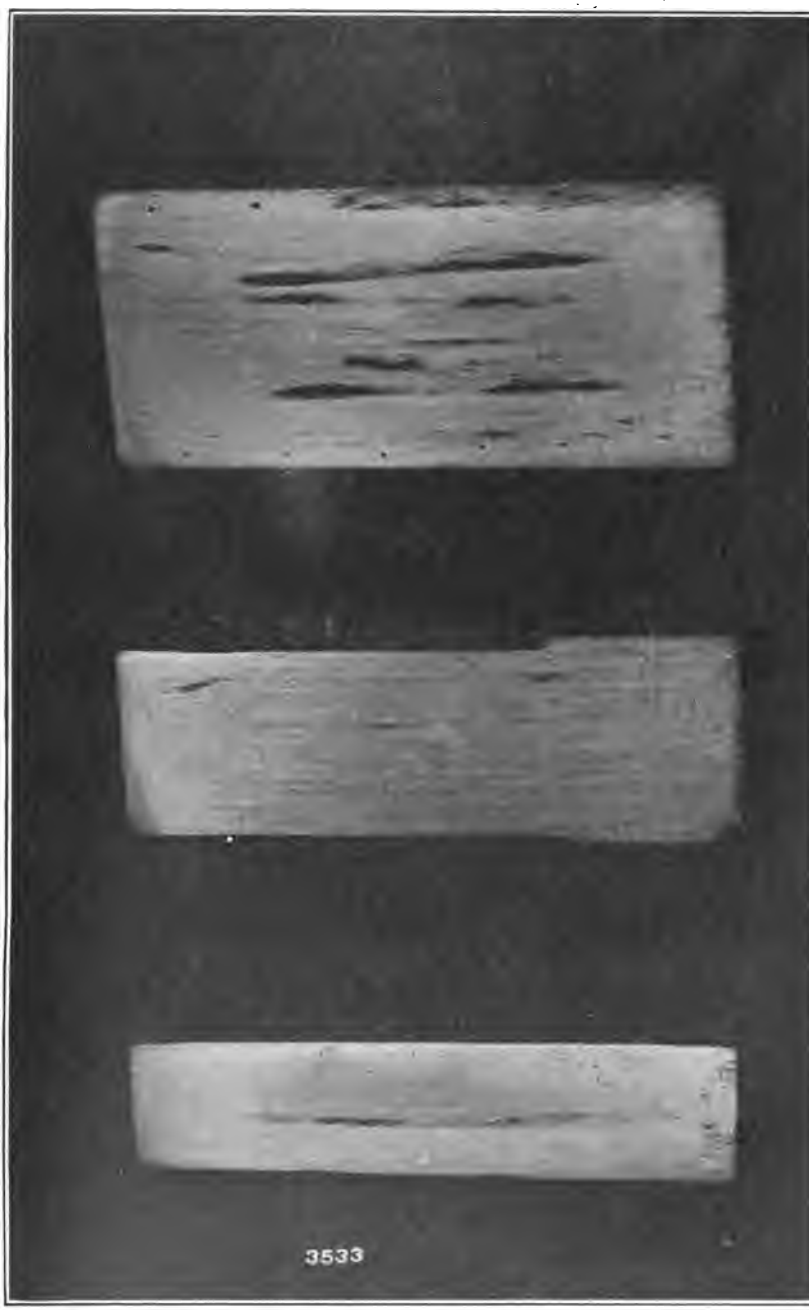
Marks.	Sectional area (square inch).	Excess angle.	Foot pounds absorbed.	Foot pounds per square inch.
16 K	0.0780	137.4	18.87	241
16 K	.0782	137.5	18.74	239
16 N	.0784	134.8	22.44	286
16 N	.0784	133.9	23.73	302
16 M	.0778	134.5	22.86	293
16 M	.0784	135.9	20.91	266
16 L	.0786	137.9	18.20	231
16 L	.0784	135.8	21.05	268

MICRO-EXAMINATION.

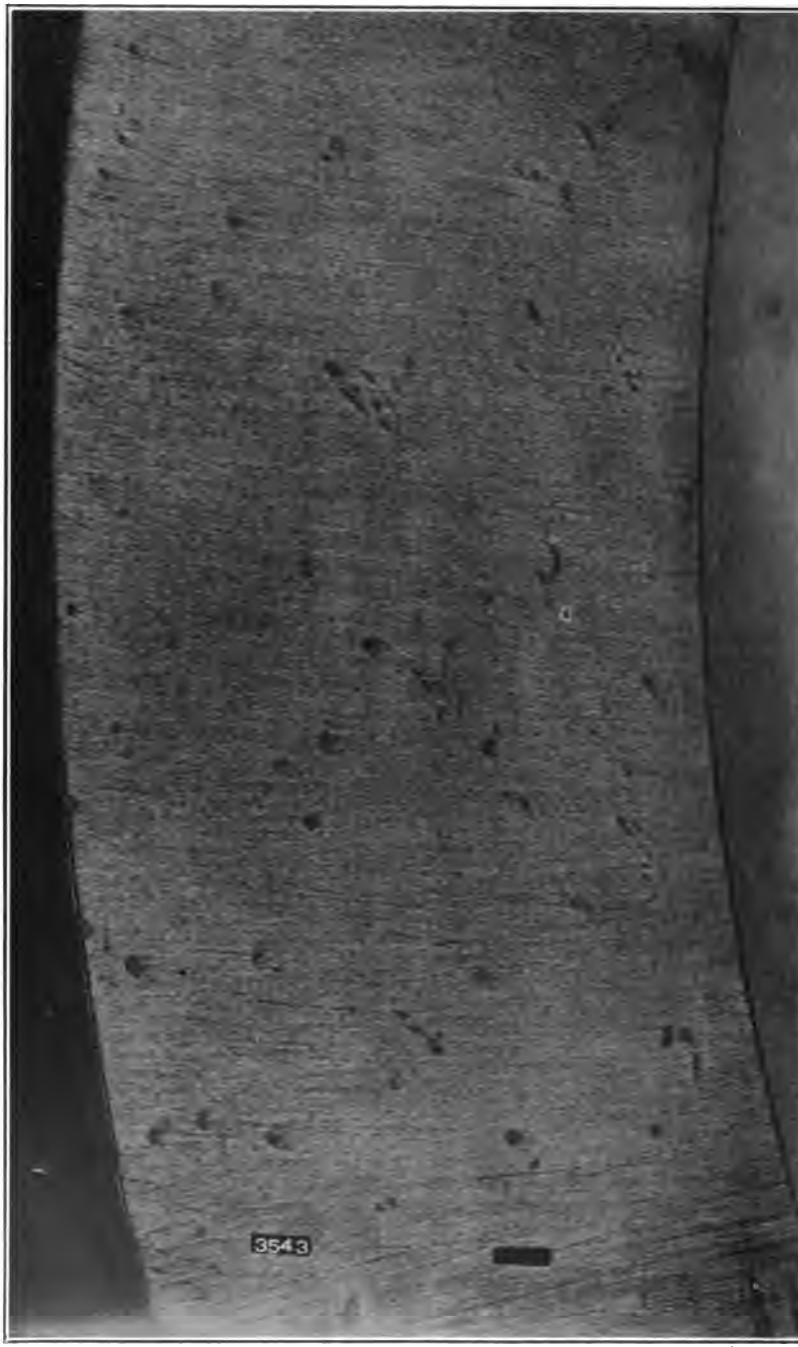
The three sections A, B, and C, shown in photograph No. 3544 were polished so as to show the streaks in a longitudinal direction. Photograph No. 3533 shows the surface after iodine etching. The streaks were left white by this treatment, and the remainder of the metal was unattacked. The nature of the lighting caused these streaks to appear dark in this photograph.

Upon etching the same specimens after repolishing, using Stead's reagent, the copper was not deposited upon the streaks.

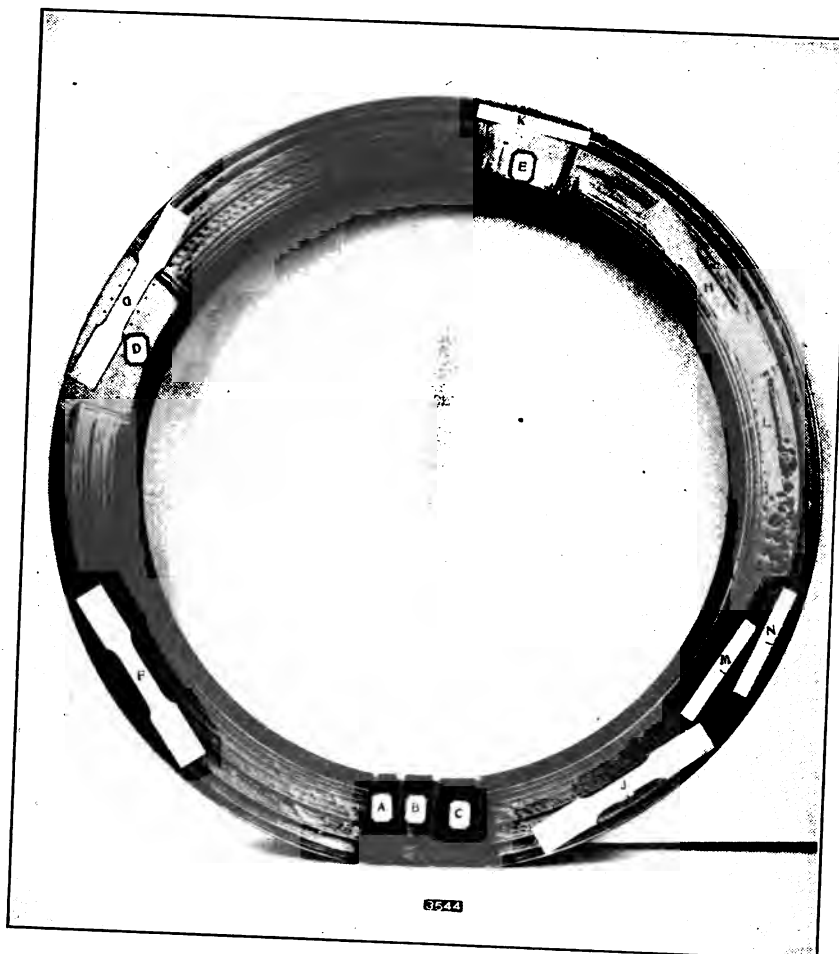
The entire end of the ring was next polished roughly with coarse emery cloth and etched with iodine. This simple polishing and etching revealed the streaks very well. Two spots marked "D" and "E" on photograph No. 3544 were next polished and etched with iodine Photograph No. 3543 shows the result of this operation.



264-I



264-2


K
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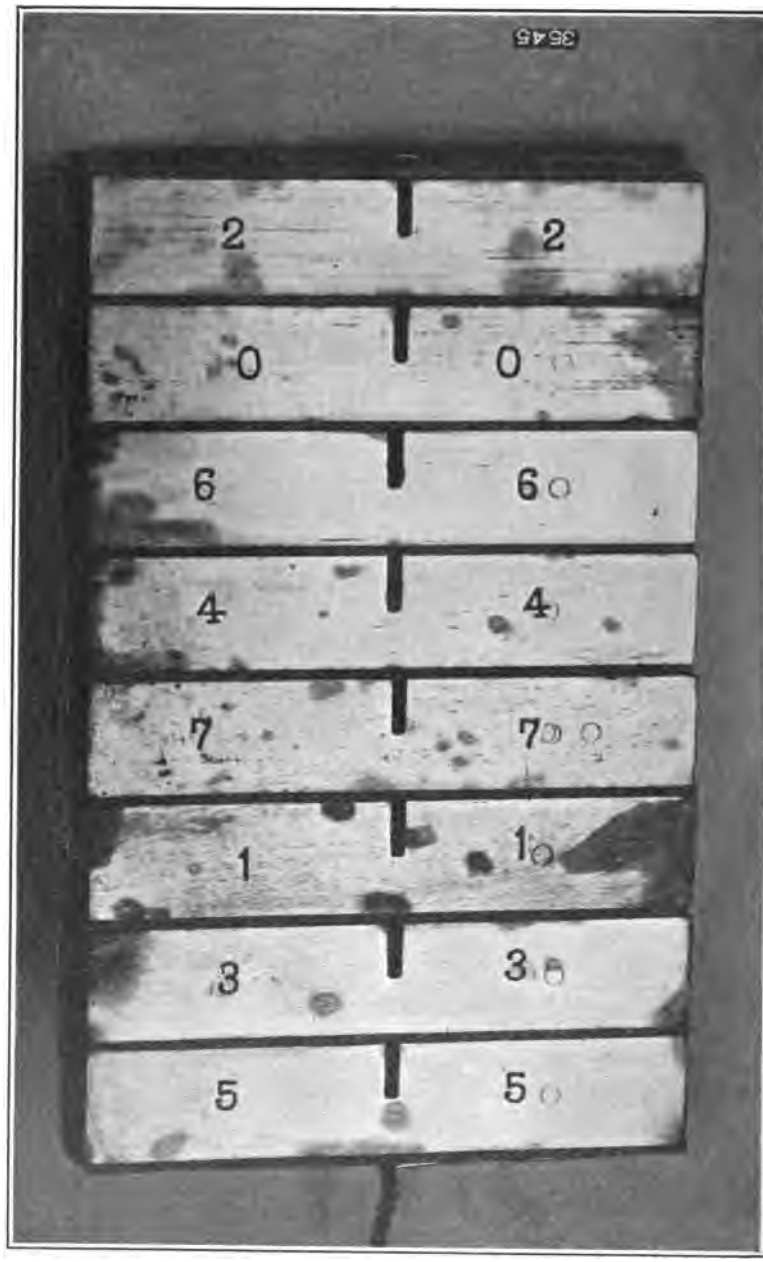
9544


3645
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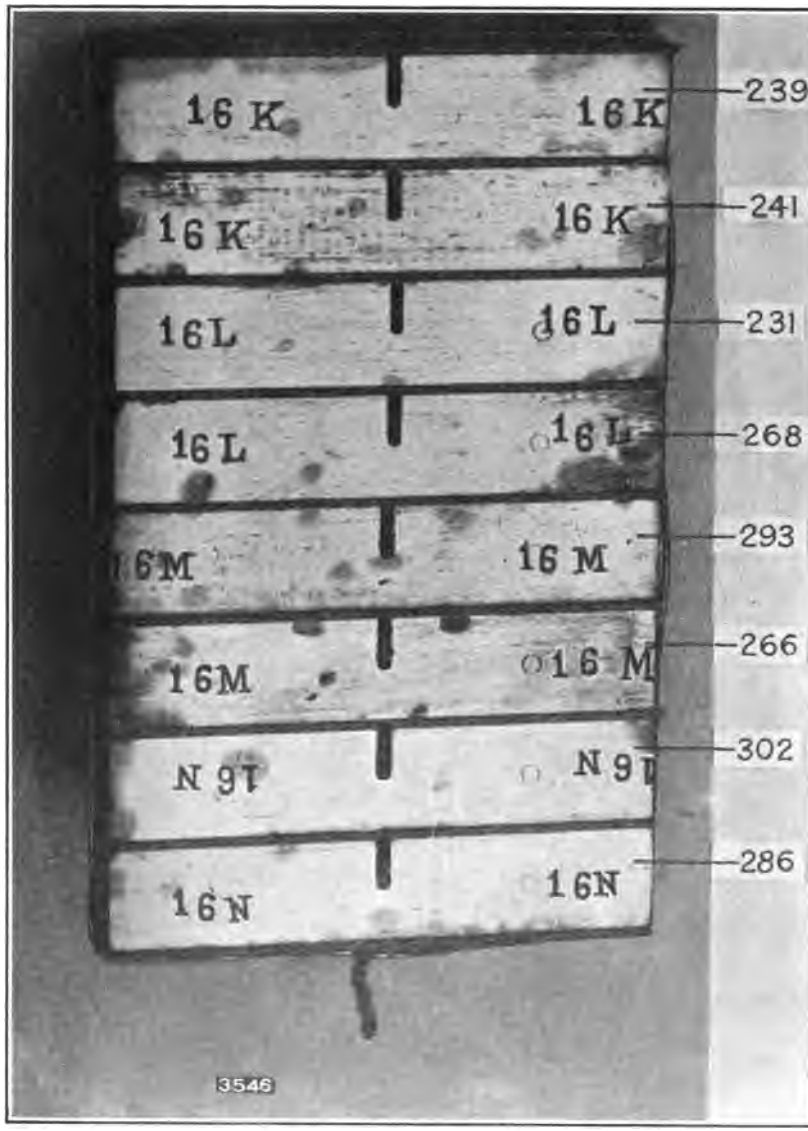
5


16 K
16 K
239
16 K
16 K
241
16L
16 L
231
16 L
16 L
268
16M
16 M
293
16M
16 M
266
N 9T
N 9T
302
16 N
16N
286
3546

264-6

31082—18——32

MICROGRAPH NO. 3535. 50 X.

Specimen A etched with Stead's reagent. Streak included in micrograph.

MICROGRAPH NO. 3536. 50 X.

Specimen A etched with HNO_3. Streak included in micrograph. Carbon content of streak lower than surrounding metal.

265-2

MICROGRAPH NO. 3538. 500 X.

Metal free from streaks.

MICROGRAPH NO. 3539. 500 X.

Located on streak. Carbon content lower than metal free from streaks.

By thus taking sections in both directions it was possible to determine the extent and nature of the streaks. It is to be concluded from the rings examined that the streaks were small and not continuous.

Specimen A was then taken for microscopic examination. Micrograph No. 3536, at 50X, shows the structure, including the streak on specimen A, after nitric acid etching. A number of elongated inclusions are present, and the carbon content of the streak is lower than that of the surrounding metal.

Micrograph No. 3535, at 50X, shows the structure on the same specimen after etching with Stead's reagent. A number of inclusions adjacent to the streak are evident.

Two micrographs at 500X are shown on plates 265–3 and 265–4. These show beyond doubt that the carbon content of the streak is lower than the carbon content of the surrounding metal. The structure is sorbitic.

REMARKS.

Due to the fact that streaked forgings are becoming common in occurrence, and due to the necessity of obtaining further information, it is thought desirable that tensile specimens be located by means of macro-etchings. An iodine etching is very simply made with a fresh alcoholic solution of iodine and the surface does not need to be highly polished. If the end of the tube from which the specimens are to be taken is etched with iodine, the tests for acceptance could be located in the most badly streaked portion.

Definite information could thus be rapidly acquired concerning the nature and extent of streaks necessary to cause failure of the metal.

PORTABLE POLISHING OUTFIT FOR METALLOGRAPHIC WORK.

OBJECT.

The object of this investigation was to develop a satisfactory grinding and polishing outfit for metallographic work.

CONCLUSIONS.

The outfit herein described is better adapted for the above work than any outfit now on the market and sold for this purpose.

EXPERIMENTAL.

The attempt was made in the design of this polishing machine to avoid the use of a flexible shaft with which some outfits are equipped, the customary construction being to connect a small motor to the necessary polishing wheels by means of a flexible shaft. The use of such a shaft brought with it its attendant difficulties and increased the weight of the outfit to an unnecessary degree.

The outfit described below was constructed by fitting a special chuck to a light motor operating on either alternating or direct current. To this chuck can be attached the emery wheel for rough polishing or the buffing wheels faced with either canvas or broadcloth, depending on the powder being used.

To enable holding the machine to the work and to secure a perfectly flat polished surface, a special guide was constructed, as shown in photographs Nos. 3653 and 3654, and drawing.

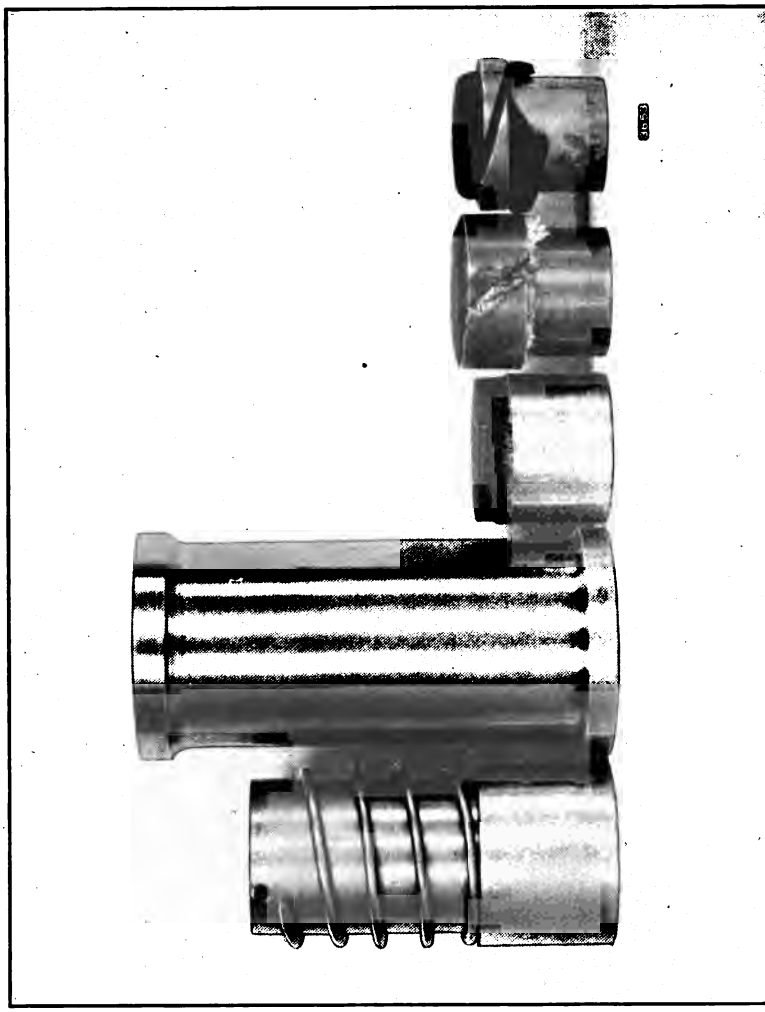
Photograph No. 3653 shows the guide before assembling and also the emery and buffing wheels.

Photograph No. 3654 shows the guide assembled and attached to the grinder. The spring is adjusted to such a tension that the grinding wheels will just touch the work when no pressure is applied. The weight of the entire outfit is 7½ pounds.

Polishing proceeds in the usual manner: (1) Rough polishing with an emery wheel to secure a flat surface; (2) canvas facing on buffer with flour emery and water for abrasive; (3) broadcloth facing with tripoli; (4) broadcloth facing with rouge for final polishing.

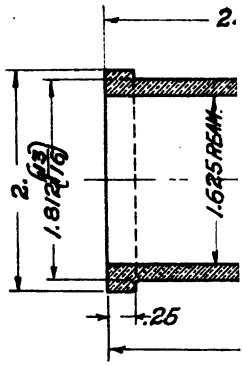
The guide not only enables the polishing of a flat surface but also prevents undue spattering of powders and water.

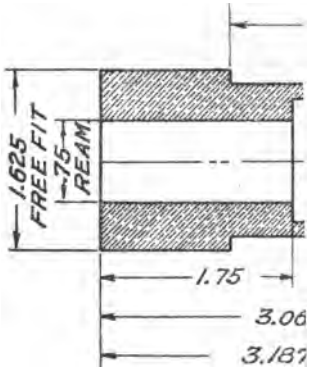
Upon trial this machine has proven satisfactory, and although not permitting of as good grade of work as can be done on a stationary machine, it enables the preparation of spots on large forgings and castings from which specimens can not be taken for microscopic examination.



266-1

266–2


2.
2.
1.812
1.625 REAM
.25


1.625
FREE FIT
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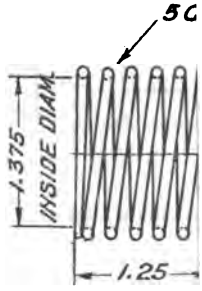
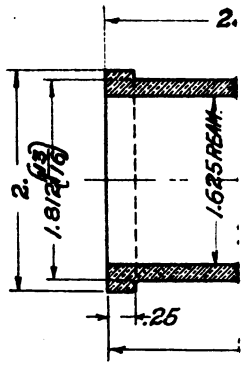
REAM
1.75
3.06
3.187


1.375
INSIDE DIAM.
1.25

ONE — SPRING

266–2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1.625 REAM
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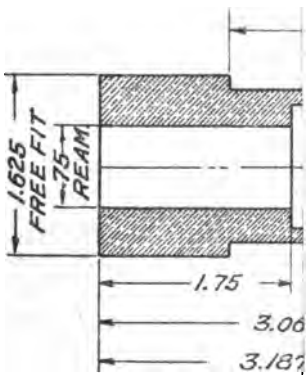
1.625
FREE FIT
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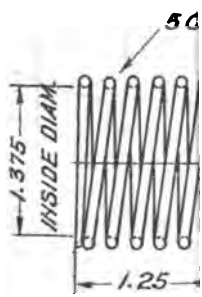
REAM
1.75
3.06
3.18


5 C
1.375
INSIDE DIAM.
1.25

ONE — SPRING

CHARPY QUALITIES OF COMMON STEEL SHELL.

OBJECT.

The object of this investigation was to determine Charpy qualities of common steel shell.

MATERIAL.

Four common steel shells with the carbon content shown were treated as follows:

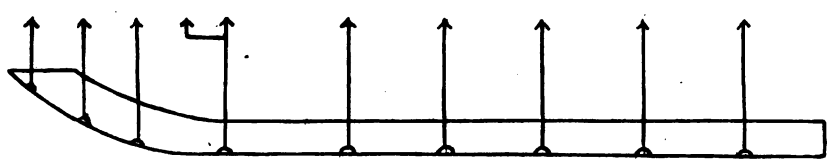
	Depth of quenching (in oil).
(1) 0.59 carbon, cavity temperature=875° C	6 inches
(2) 0.58 carbon, cavity temperature=875° C	6 inches
(3) 0.74 carbon, annealed at 825° C. before machining; cavity temperature=825° C	5 inches
(4) 0.63 carbon, annealed at 825° C. before machining; cavity temperature=825° C	5 inches

CONCLUSIONS.

The outside specimens in shells 1, 2, and 3 gave higher Charpy tests than the inside specimens. Shell No. 4 gave the reverse results. Shell No. 3, 0.74 carbon, gave a mean Charpy of 28.5, whereas shell No. 1, 0.59 carbon, and shell No. 2, 0.58 carbon, gave mean Charpy figures of 126 and 93.5, respectively.

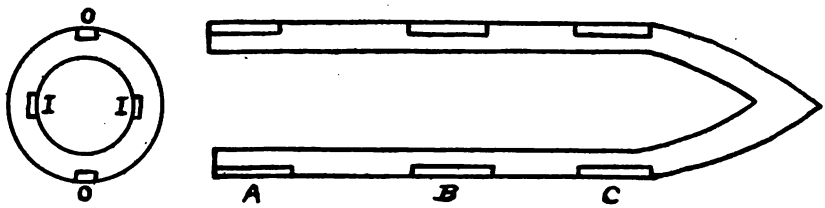
The general conclusion can be drawn that a 0.70 carbon 4.7-inch common steel shell manufactured as indicated under "Material" will have approximately one-third the Charpy strength of a 0.50 carbon common steel shell manufactured as indicated in this report.

The Brinell hardness was taken on these shells at points 2 inches apart. The scleroscope was used on the ogive. The results obtained are recorded in the following table. It is to be noted that shell No. 4 has a very irregular hardness.



Shell No.	Carbon (per cent).	Brinell.	Brinell.	Brinell.	Brinell.	Brinell.	Brinell.	S. Scl.	S. Scl.	S. Scl.	S. Scl.
1	0.59	207	207	207	212	217	235	40	53	50	49
2	.58	202	202	202	202	212	229	40	45	45	45
3	.74	235	235	235	235	235	248	40	60	58	56
4	.63	217	223	217	229	229	248	40	61	61	50

Twelve Charpy specimens were then cut from each shell as located in accompanying sketch. The results of these tests are tabulated below.



Shell No.	Location of specimen.					
	AO.	AI.	BO.	BI.	CO.	CI.
1	153	170	149	76	92	64
	179	104	146	103	114	64
Mean	166	137	147.5	89.5	103	64
2	195	109	93	49	92	78
	114	109	71	54	80	79
Mean	154	109	82	52	86	78.5
3	30	39	27	25	25	25
	36	28	27	27	27	26
Mean	33	33.5	27	26	26	25.5
4	42	213	77	135	59	54
	00	151	39	121	29	153
Mean	21	182	58	128	44	103

Table of mean values.

Shell No.	Inner specimen.	Outside specimen.	Mean of inner and outer.
1	96.8	138.8	117.8
2	79.8	107.0	93.4
3	28.3	28.6	28.5
4	137.7	41.0	89.3

PRIVATE TESTS.

PRIVATE TESTS.

Tests made for private parties during the fiscal year ended June 30, 1917.

Date.	Material.	Name.	City and State.
1916.			
July 21	Steel	The Barney & Smith Car Co	Dayton, Ohio.
31	Taylor bar iron	B. M. Jones & Co. (Inc.)	Boston, Mass.
Aug. 2	Buoy shackles	Chapman & Brewster	Portland, Me.
10	Steel	Sauveur & Boylston	Cambridge, Mass.
18	....do	Jones & Laughlin Steel Co	Pittsburgh, Pa.
22	Cast-iron bars	Davis & Farnum Manufacturing Co.	Waltham, Mass.
22	Steel	Sauveur & Boylston	Cambridge, Mass.
29	Columns	United States Column Co	Do.
Sept. 1	Taylor bar iron	B. M. Jones & Co. (Inc.)	Boston, Mass.
18	....do	....do	Do.
18	Brackets on column	United States Column Co	Cambridge, Mass.
23	Concrete building block	The Dry-Wall-Block Co. (Inc.)	Buffalo, N. Y.
25	Steel bars	Hood Rubber Co	Watertown, Mass
28	Hollow tiles	The Whiteacre Fireproofing Co	Waynesburg, Ohio.
29	Concrete cubes	Town of Westfield	Westfield, Mass.
29	Concrete building block	Watertown Construction Co	Watertown, Mass.
Oct. 3	....do	A. J. Switzer	Gardenville, N. Y.
5	Steel	Gulick-Henderson Laboratory	Pittsburgh, Pa.
13	Concrete building block	Harry Mahoney	Salem, Mass.
13	....do	Watertown Construction Co	Watertown, Mass.
17	Hollow tiles	The Whiteacre Fireproofing Co	Waynesburg, Ohio.
17	Building bricks	Gamble & Stockton Co	Jacksonville, Fla.
30	Concrete building block	The Dry-Wall-Block Co. (Inc.)	Buffalo, N. Y.
Nov. 9	Rope	Harrington-King & Co	Boston, Mass.
13	Taylor iron	B. M. Jones & Co. (Inc.)	Do.
16	Concrete building block	John Delaney	Somerville, Mass.
20	....do	John Quigley	Do.
21	Steel	Bethlehem Steel Co	South Bethlehem, Pa.
25	....do	The Lundin Steel Casting Co	Neponset, Mass.
Dec. 11	Aluminum bronze	Sauveur & Boylston	Cambridge, Mass.
18	Chain hooks	Bethlehem Steel Bridge Corporation.	Steelton, Pa.
18	Concrete building block	New Bedford Waterproof Building Block Co.	New Bedford, Mass.
18	Concrete cubes	Town of Westfield	Westfield, Mass.
26	Taylor iron	B. M. Jones & Co. (Inc.)	Boston, Mass.
27	Steel	The Hydraulic Pressed Steel Co	Cleveland, Ohio.
27	Wire attachment ends	The Burgess Co	Marblehead, Mass.

Tests made by private parties during the fiscal year ended June 30, 1917—Continued.

Date.	Material.	Name.	City and State:
1917.			
Jan. 2	Steel	Gulick-Henderson Co	Pittsburgh, Pa.
3	do	The Lundin Steel Casting Co	Neponset, Mass.
9	Columns	United States Column Co	Cambridge, Mass.
10	Bricks	Fiske & Co. (Inc.)	New York, N. Y.
19	Building bricks	Waldo Bros. (Inc.)	Boston, Mass.
24	Chain	The Bridgeport Chain Co	Bridgeport, Conn.
27	Concrete cylinders	Boston Transit Commission	Boston, Mass.
31	Column	United States Column Co	Cambridge, Mass.
Feb. 6	Plate steel	E. McCabe & Co	Lawrence. Mass.
7	Chain	The Bridgeport Chain Co	Bridgeport, Conn.
7	Hollow tiles	The Malvern Fire Clay Co	Malvern, Ohio.
9	Steel	Camden Forge Co	Camden, N. J.
15	Concrete cross-arms	American Concrete Products Co.	Boston, Mass.
21	Plate steel	E. McCabe & Co	Lawrence, Mass.
28	Concrete cylinders	Boston Transit Commission	Boston, Mass.
28	Blocks	The Bridgeport Stone Co	Bridgeport, Conn.
Mar. 1	Steel	Sauveur & Boylston	Cambridge, Mass.
6	Columns with steel plates	United States Column Co	Do.
8	Steel	Sauveur & Boylston	Do.
13	do	do	Do.
17	Steel bearing link	E. & T. Fairbanks & Co	St. Johnsbury, Vt.
30	Concrete cylinders	Boston Transit Commission	Boston, Mass.
30	Steel	Poole Engineering & Machine Co.	Baltimore, Md.
30	Concrete building blocks	G. Rappoli	Medford, Mass.
Apr. 2	Steel	Sauveur & Boylston	Cambridge, Mass.
6	do	The Metal Products Co	Beaver, Pa.
11	do	Washington Steel & Ordnance Co.	Washington. D. C.
17	Rope	Columbian Rope Co	Boston, Mass.
May 10	Steel	Federal Steel Foundry Co	Do.
15	Concrete building blocks	Frank Perrelli	Buffalo, N. Y.
15	do	Andrew Sordell	Do.
15	do	Frank M. Krenger	Do.
16	Column	G. Bush	Revere, Mass.
16	Steel	Sauveur & Boylston	Cambridge, Mass.
18	do	National Forge & Tool Co	Erie, Pa.
24	do	International Steel & Ordnance Corporation.	New York, N. Y.
29	do	National Tube Co	McKeesport, Pa.
June 8	do	International Engineering Works (Ltd.).	Framingham, Mass.
12	do	Boston Forge Co	Boston, Mass.
22	do	International Steel & Ordnance Corporation.	New York, N. Y.
23	Bronze fuze plug	Waltham Watch Co	Waltham, Mass.
26	Cast-iron cube	The Turner & Seymour Manufacturing Co.	Torrington, Conn.
29	Concrete building block	G. Cannizaro	Somerville, Mass.

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